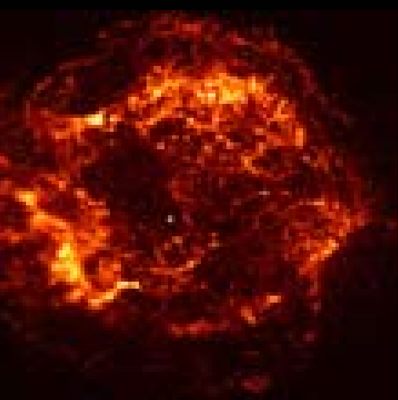
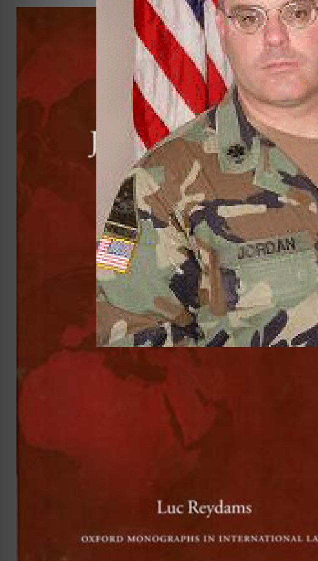
Nuclear Warfare

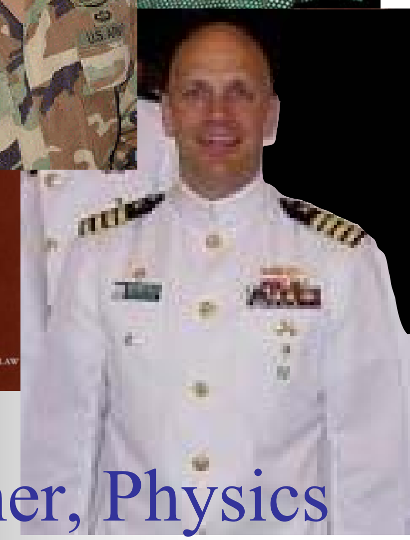
PHYSICS 20061

Michael Wiescher

Lecturers







Michael Wiescher, Physics
Luc Reydams, Law
Margaret Pfeil, Theology
Kelly Jordan, ROTC Army
Mike Neller, ROTC Navy

In addition a series of topic related talks will be given by guest speakers.

http://www.nd.edu/~nsl/Lectures/nuclear/index.htm


you guys

Syllabus

The course on Nuclear Warfare PHYS 20061 is offered by the Physics Department and the Center for Social Concerns as an introductory course for non-science majors to provide an overview about the broad range of topics and aspects of nuclear weapons and warfare in the 20th century.

Class Content

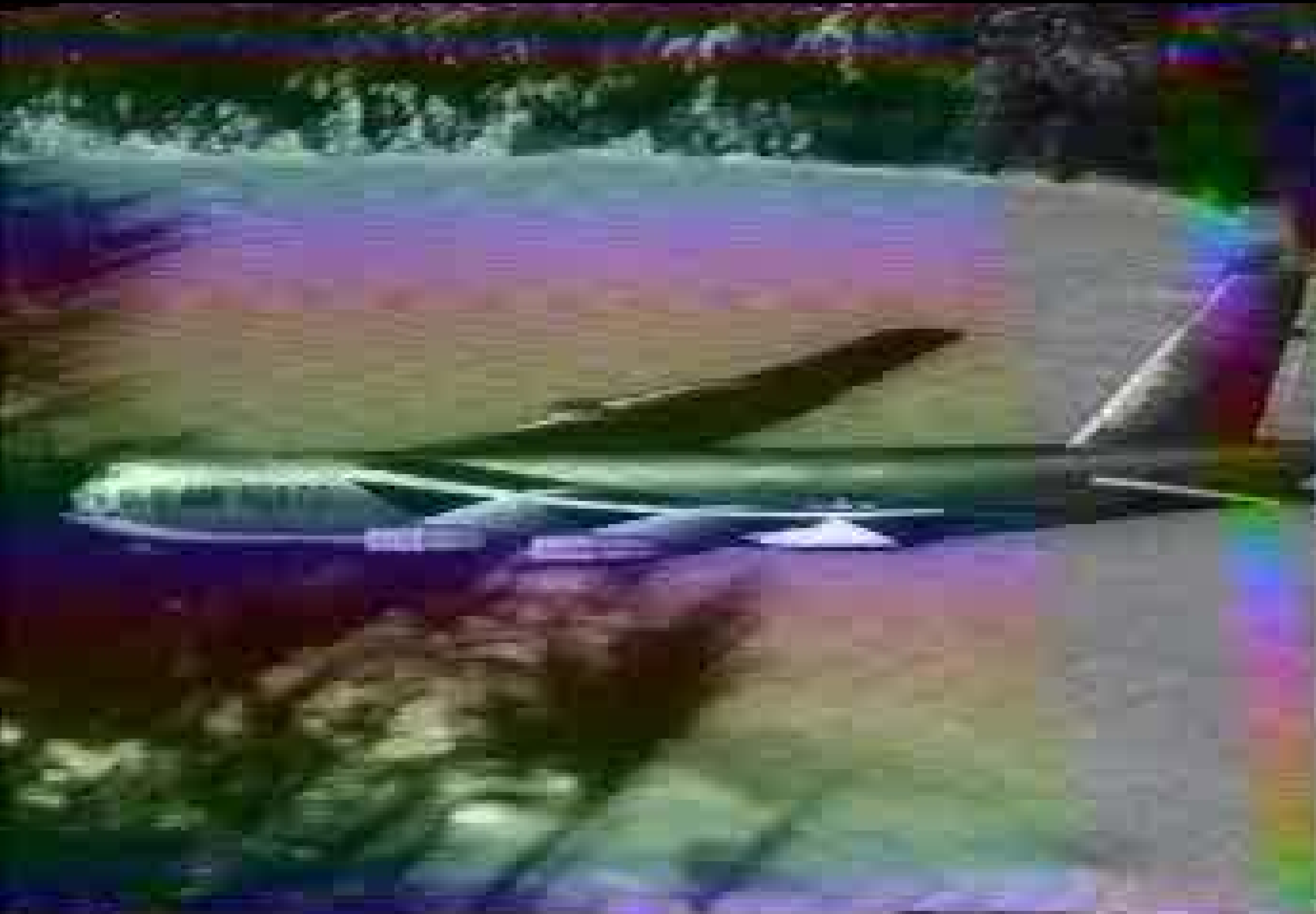
The course will start with the history and emergence of weapons of mass destruction technologies as a consequence of World War I and World War II, culminating in the development and use of the nuclear bomb. This will be followed by a discussion of the underlying physics principles to provide the necessary background for a basic understanding of nuclear weapons techniques and nuclear weapons effects as well as the decay radiation driven consequences. These consequences will be discussed in terms of short-range, atmospheric, biological, and medical effects together with the implications for social groups and societies. This will be followed by an extensive discussion of the legal, political, and ethical implications of possession and use of nuclear weapons and nuclear warfare.

Class Content

1. ***History of Nuclear Bomb development***
   History of nuclear physics
   Mindset for WMD technology emerging in WW I and WW II
   Technological break through by development of military industrial complex
   Building the bomb as national effort, the US Manhattan project and the Arzamas Russian bomb project
2. ***Physics of Nuclear Bomb***
   Nuclear physics principles
   Nuclear energy release
   Nuclear decay and radiation
   Nuclear fission processes
   Nuclear fusion processes
3. ***Technology of Nuclear Bomb***
   Design technology
   Efficiency concept
   Neutron bomb
4. ***The consequences of Nuclear Bombs***
   Shock and temperature effects (classical physics)
   Fall out effects and radiation level
   Atmospheric impact
   Nuclear Winter

Class Content

5. ***Nuclear Radiation Effects***
   Natural radiation
   Man-made radiation
   Biological impact
   Medical consequences
   Hiroshima and Nagasaki
6. ***The legal aspects of Nuclear Weapons***
   Nuclear Arms Control
   Nuclear Disarmament
   Non-proliferation policies and treaties
   The legality of Nuclear Weapon use
7. ***Moral and Ethical Aspects of Nuclear Weapons***
   The moral conflict
   “evil” as moral justification
   catholic social traditions and the response of the church
8. ***Nuclear weapons technology and small communities***
   The economic impact of nuclear weapon industry
   The impact of nuclear weapon testing
   Protecting the community
   The response of communities in press and opposition



Fact Sheet

- **28,800:** The total number of intact nuclear warheads retained by the United States and Russia.
- **30,000:** Number of intact nuclear warheads throughout the world. 17,500 of these are operational.
- **128,000+:** Estimated number of nuclear warheads built worldwide since 1945. All but 2 percent of these nuclear warheads have been built by the United States (55 % or 70,000+) and Russia (43 % or 55,000+).
- **10,729:** Total number of intact U.S. nuclear warheads (274 warheads are awaiting dismantlement)
- **10,455:** Total warheads in the U.S. stockpile
- **~7,000:** Number of operational strategic U.S. nuclear weapons
- **~1,600:** Number of U.S. tactical nuclear weapons (~800 of these are operational)
- **8,400:** Total number of operational nuclear warheads in Russian arsenal
- **5,000:** Approximate number of Russian strategic nuclear weapons
- **3,400:** Approximate number of operational Russian tactical nuclear weapons (total tactical arsenal said to comprise as many as 10,000+ weapons)
- **3,500:** Approximate number of strategic U.S. nuclear weapons, year 2003 under START II.
- **3,000:** Approximate number of strategic Russian nuclear weapons, year 2003 under START II.
- **~2,000:** Maximum number of deployed strategic nuclear weapons that will remain in the U.S. and Russian arsenals by 2012
(The Treaty of Moscow (also known as SORT) signed by U.S. President George W. Bush and Russian President Vladimir Putin in May 2002.
- **10,000:** The number of warheads the United States will retain in 2012 (essentially the same number as today)

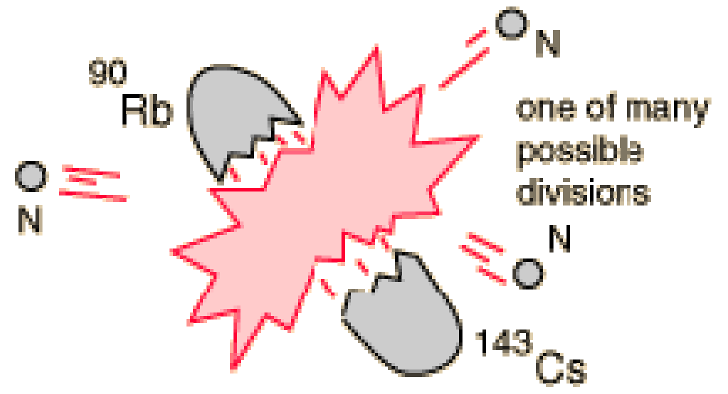
- **$3.5 trillion:** Amount the United States spent between 1940 and 1995 to prepare to fight a nuclear war.
- **$27 billion:** Amount the United States spends annually to prepare to fight a nuclear war.
- **$2.2 billion:** Cost for one B-2 bomber (21 were authorized by Congress).
- **$2.5 billion:** The lifecycle cost of each B-2 (RDT&E, procurement, operations, maintenance, support).

The figures cited above were gathered with the aid of resources from the National Resources Defense Council (NRDC): website. *www.nrdc.org*

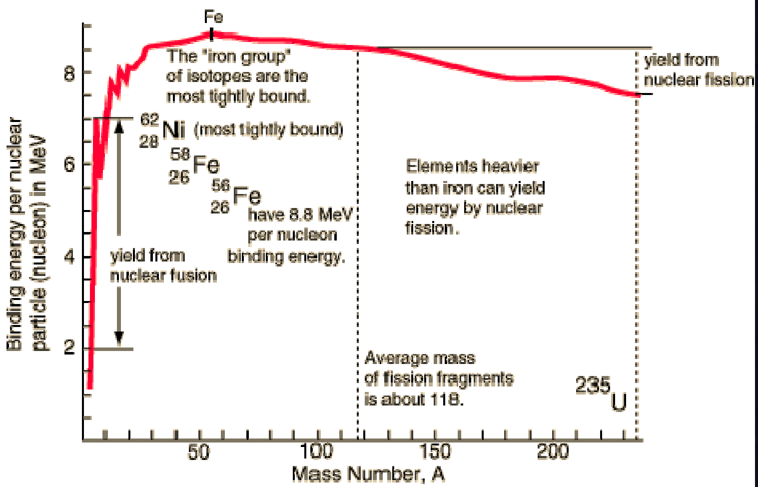
The History of warfare in the 20th century

REPUBLIQUE DU CONGO
POSTES 2000
150F
PIERRE CURIE (1859-1906)
MARIE CURIE (1867-1934)
АЛБЕРТ АЈНШТАЈН (1879-1955)
1,50
E=mc²
РЕПУБЛИКА СРПСКА
БОЈАНИЋ/СКОЧАЈИЋ
2004
ФОРУМ
ALBERT EINSTEIN (1879-1955)
125 ГОДИНА ОД РОЂЕЊА АЛБЕРТА АЈНШТАЈНА
1871-1937
1971
ПОЧТА СССР
ЭРНЕСТ РЕЗЕРФОРД
6К
Max Planck proposes Quantum Theory of Energy
MILLENNIUM
The Gambia
D 3
NIELS BOHRS ATOMTEORI
1913-1963
hν = ε₂ - ε₁
DANMARK
60
V. BANG del.
CZ. SLANIA sc.
300
Δp·Δq~h
Heisenbergsche Unschärferelation
Deutschland
1,53 €
Werner Heisenberg
Physiker
1901 - 1976
2001
ST. VINCENT & THE GRENADINES
20¢
MILLENNIUM 2000
1938: The discovery of Fission
St. VINCENT
$1
ERNEST LAWRENCE – Nuclear physics
1942-ENRICO FERMI
PRIMUL REACTOR NUCLEAR
2100 LEI
ROMÂNIA
millenium secolul XX
2000
E.D. CARTIS
BELGIË
BELGIQUE
17
0,42

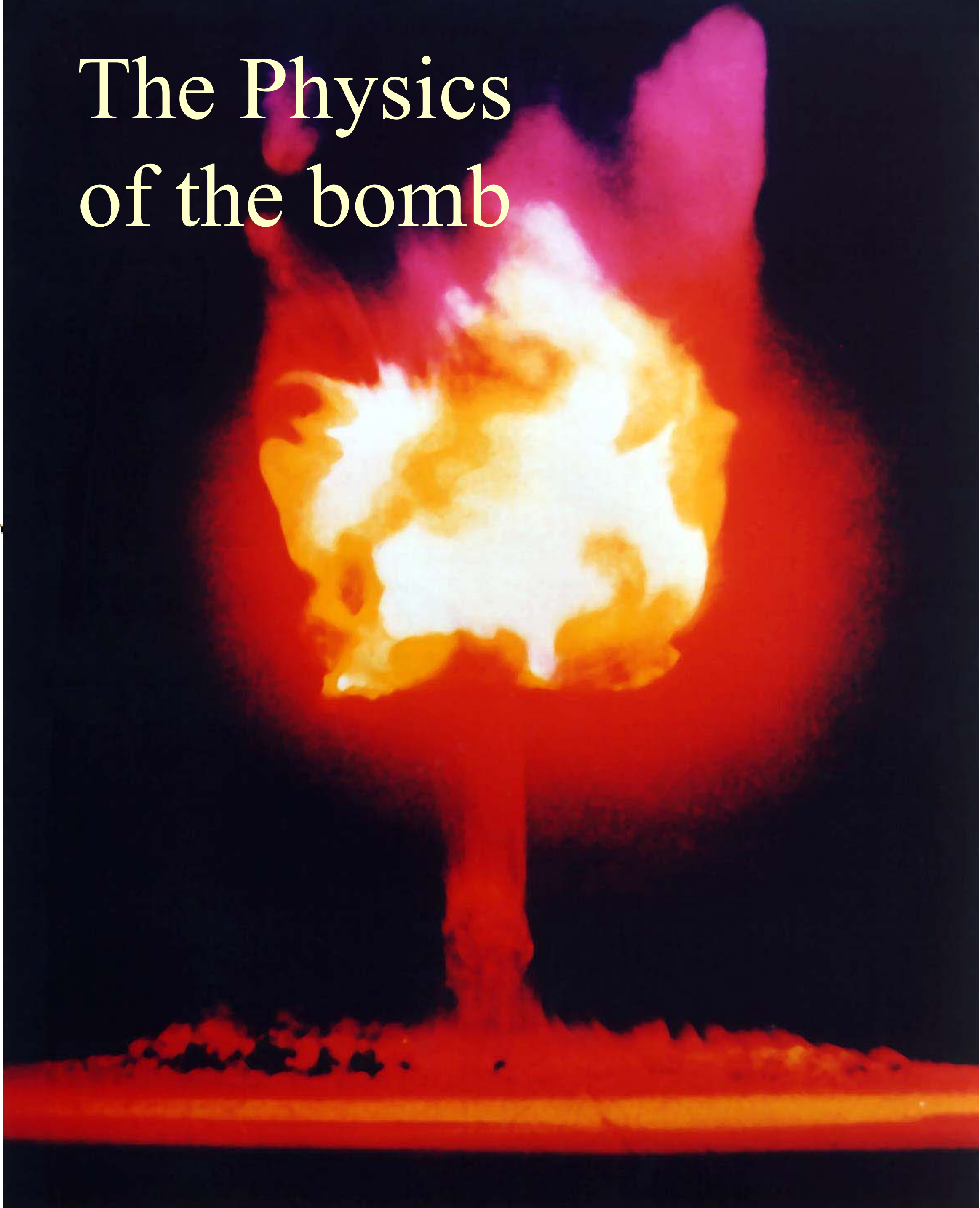
The Physics of the bomb



^{235}U Fission



Deuterium-Tritium Fusion

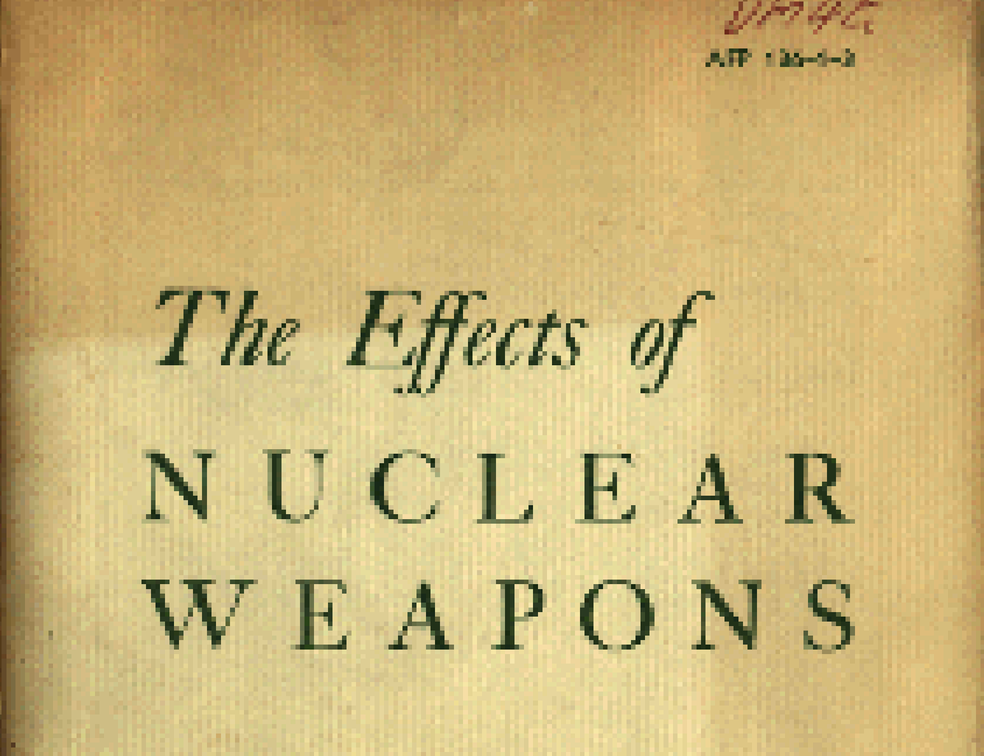


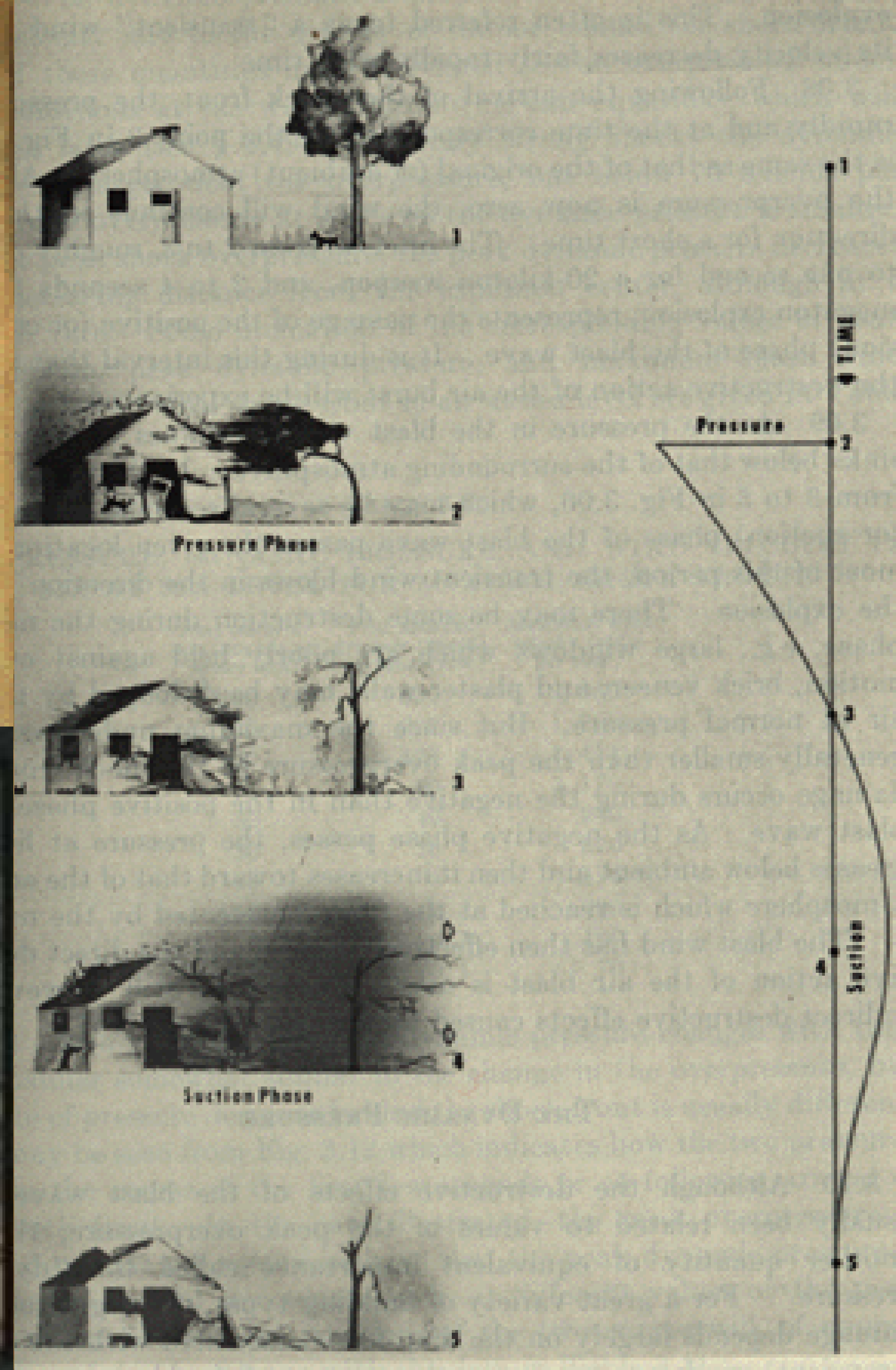
Technical Design of Bomb


GAMMA-RAY CREATURES LOOSE!
PAUL DOUGLAS
EVA BARTOK
"the gamma people"
A COLUMBIA PICTURE


THIS was the deadliest secret of all . . .
The MAN with the RADIO-ACTIVE BRAIN!
ALLIED ARTISTS presents
The ATOMIC MAN
starring
GENE NELSON · FAITH DOMERGUE
A TODON PRODUCTION
CHARLES ERIC MAINE

The Bomb Show
the weapon test series 1945-1963


The Effects of
NUCLEAR
WEAPONS

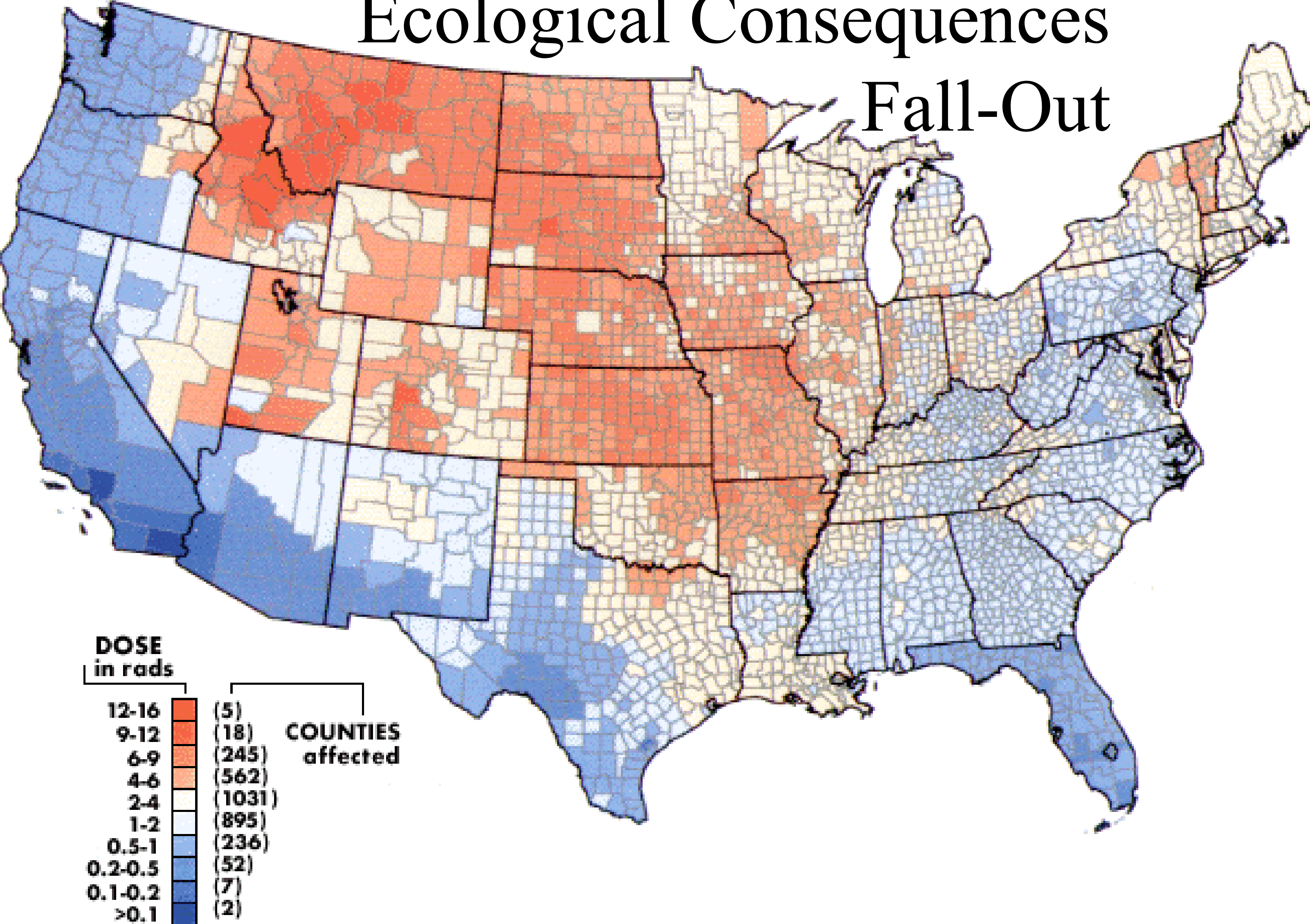

Pressure Phase
Suction Phase
Pressure
TIME
Suction

Medical Consequences

"*Lethal effects of radiation* can be summarized briefly: a very high dose (5000 rads +) causes death in hours; a smaller but lethal dose (400 rads +): death in weeks. In the latter case, sickness starts with diarrhea and vomiting, followed by some temporary improvement, and then the same symptoms recur with the addition of hemorrhage, anemia, infections, and a slow death."

The U.S. "Federal Emergency Management Agency" predicts approximately 86,000,000 people dead and 34,000,000 severely injured in the United States. There are about 2,000,000 hospital beds in Canada and U.S.A. combined.

Ecological Consequences
Fall-Out



International Nuclear Weapon Treaties

Treaty on the non-proliferation of nuclear weapons (1968)
Entered into force March 5, 1970

The States concluding this Treaty, hereinafter referred to as the "Parties to the Treaty",

Considering the devastation that would be visited upon all mankind by a nuclear war and the consequent need to make every effort to avert the danger of such a war and to take measures to safeguard the security of peoples,

Believing that the proliferation of nuclear weapons would seriously enhance the danger of nuclear war,

In conformity with resolutions of the United Nations General Assembly calling for the conclusion of an agreement on the prevention of wider dissemination of nuclear weapons,

Personal Conscience

“Thou shalt not kill”

The Bomb Test Series

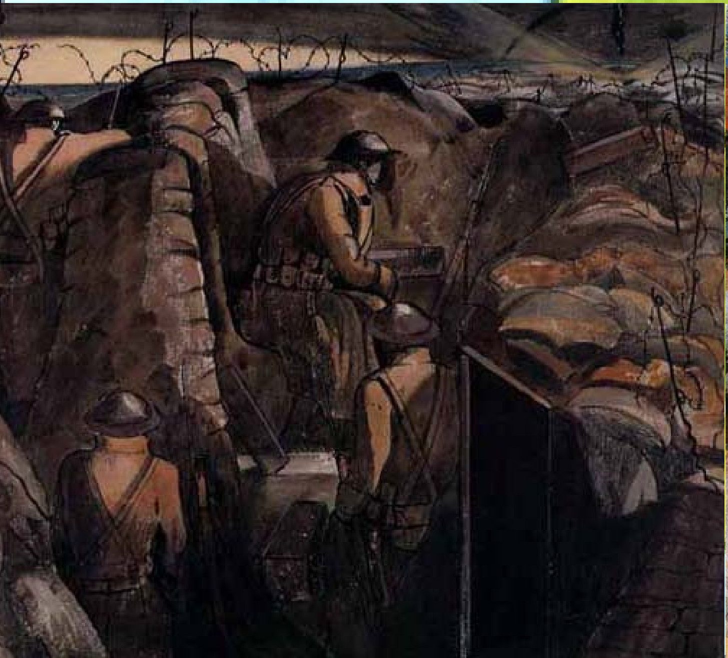
Scientific Hubris?

Modern Warfare in the 20th Century

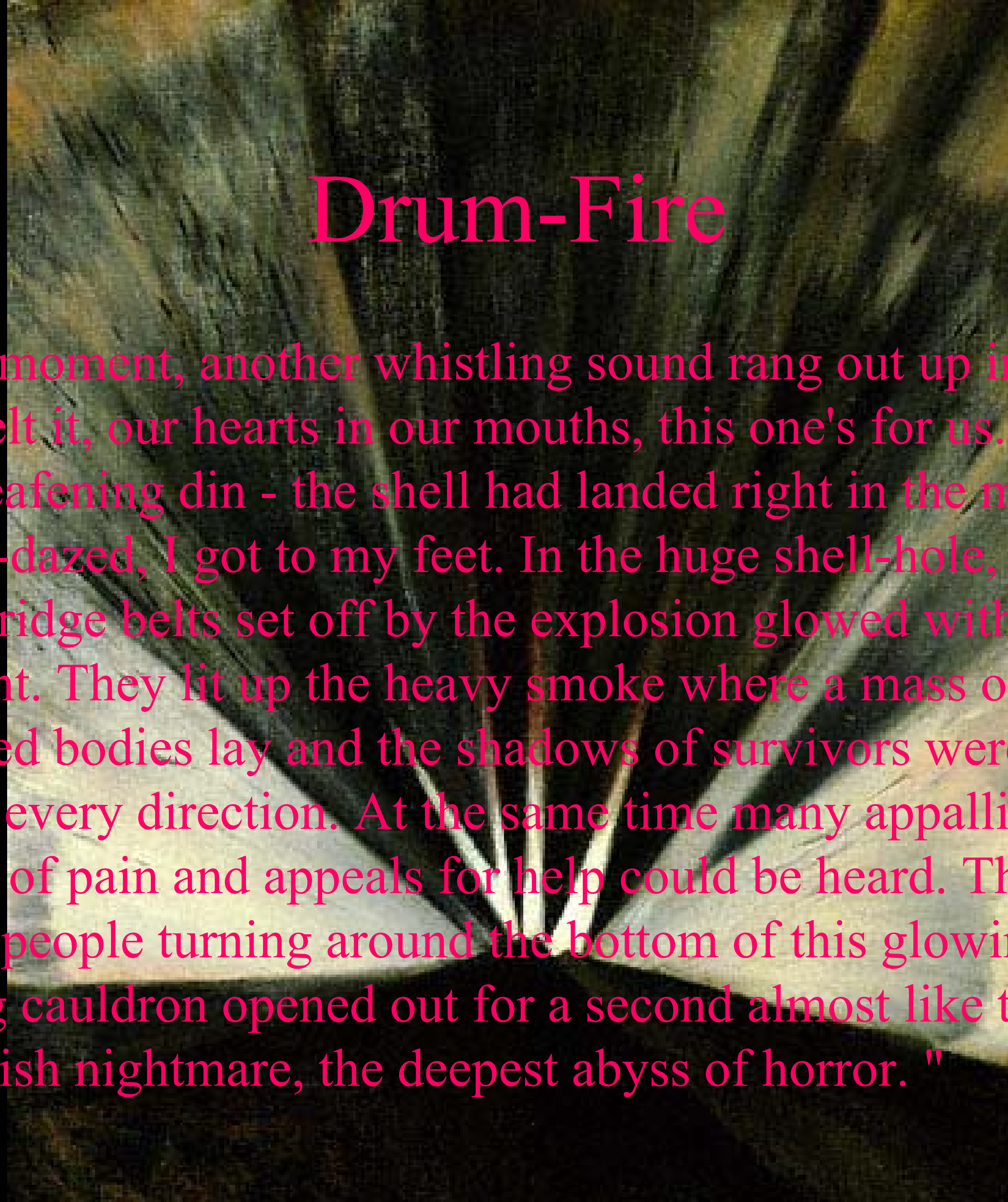
The development of weapons research
The development of weapons laboratories
The emergence of modern science

World War I Trenches

Marne 1914
Ypres 1915
Verdun 1916
Somme 1916
Cambrai 1917
Ludendorff 1918



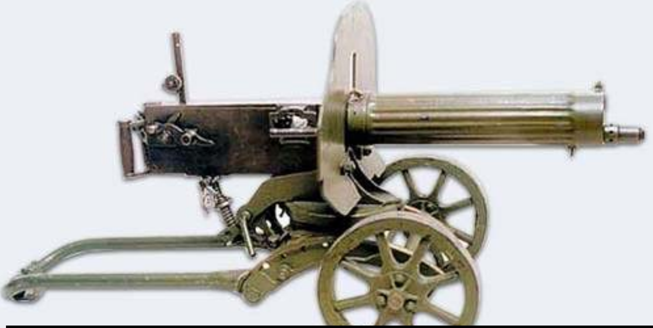
Trench War



Drum-Fire

At that moment, another whistling sound rang out up in the air; we all felt it, our hearts in our mouths, this one's for us. Then a huge, deafening din - the shell had landed right in the midst of us. Half-dazed, I got to my feet. In the huge shell-hole, machine-gun cartridge belts set off by the explosion glowed with a crude pink light. They lit up the heavy smoke where a mass of twisted blackened bodies lay and the shadows of survivors were running away in every direction. At the same time many appalling screams of pain and appeals for help could be heard. The dark mass of people turning around the bottom of this glowing, smoking cauldron opened out for a second almost like the vision of a hellish nightmare, the deepest abyss of horror. "

Before attacks and offensives took place, heavy artillery was used to soften up the enemy trenches. At the offensive at the Somme in the summer of 1916 General Douglas Haig ordered an eight-day preliminary bombardment before sending 750,000 men (27 divisions) to attack the German trenches. The following year, Haig decided on a ten day bombardment during the offensive at Ypres. This barrage involved 3,000 guns firing 4,283,550 shells at the German defenses.



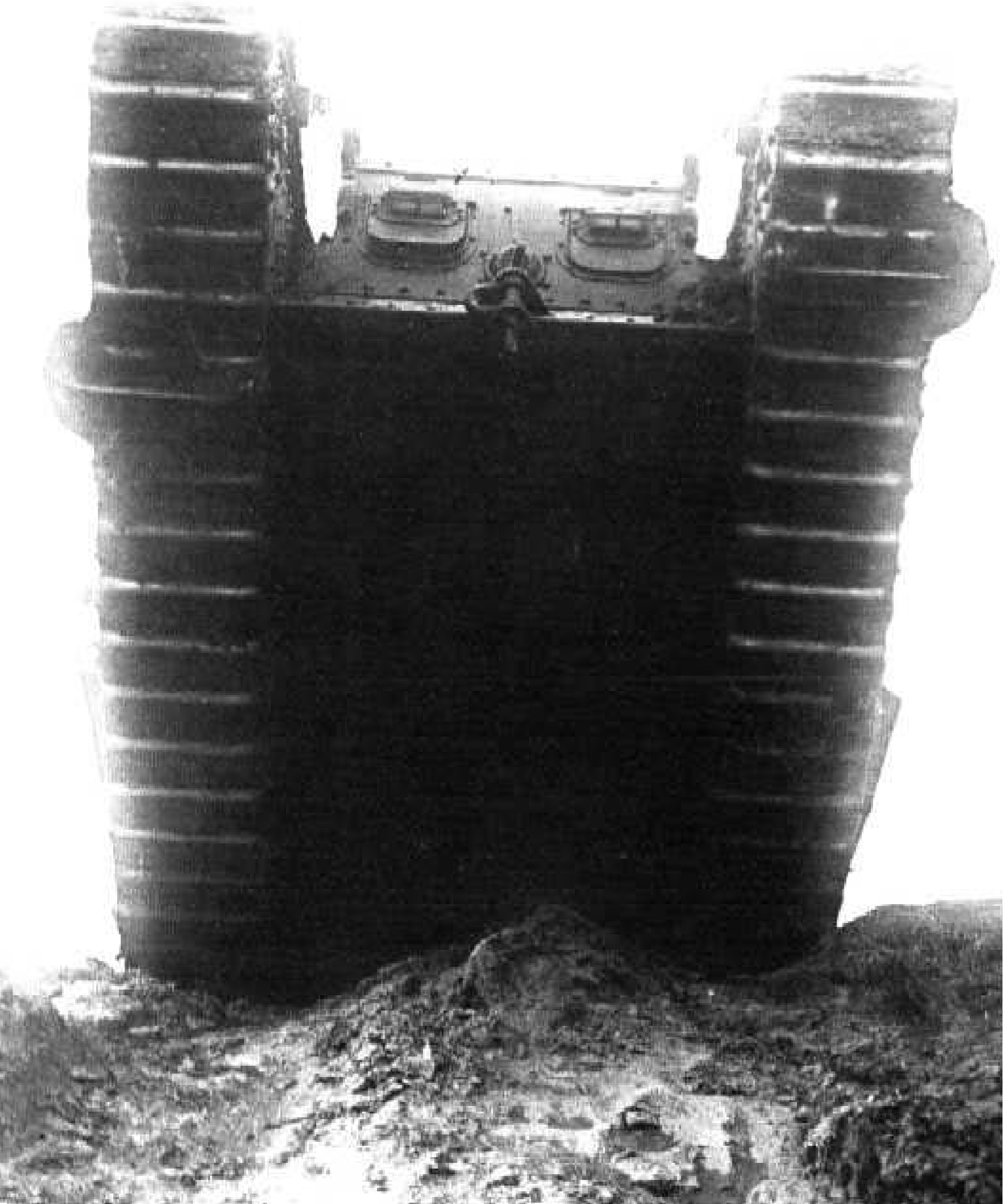
Machine Guns

In 1881 Hiram Maxim, an American inventor visited the Paris Electrical Exhibition. While at the exhibition he met a man who told him: "If you wanted to make a lot of money, invent something that will enable these Europeans to cut each other's throats with greater facility."

The 1914 machine gun weighted between 30 kg-60 kg. It was usually positioned on a flat tripod and would require a gun crew of four to six operators. In theory they could fire 400-600 small-caliber rounds per minute, a figure that was to more than double by the war's end, with rounds fed via a fabric belt or a metal strip. The shooting distance ranged from 2000 to 4000 yards. The disadvantage was rapid overheating during use which requires initially constant water cooling until air cooling was maiximized.

Machine Guns stopped infantry attacks and maintained trench war conditions!

Nearly 40% of casualties was caused by machine gun fire!

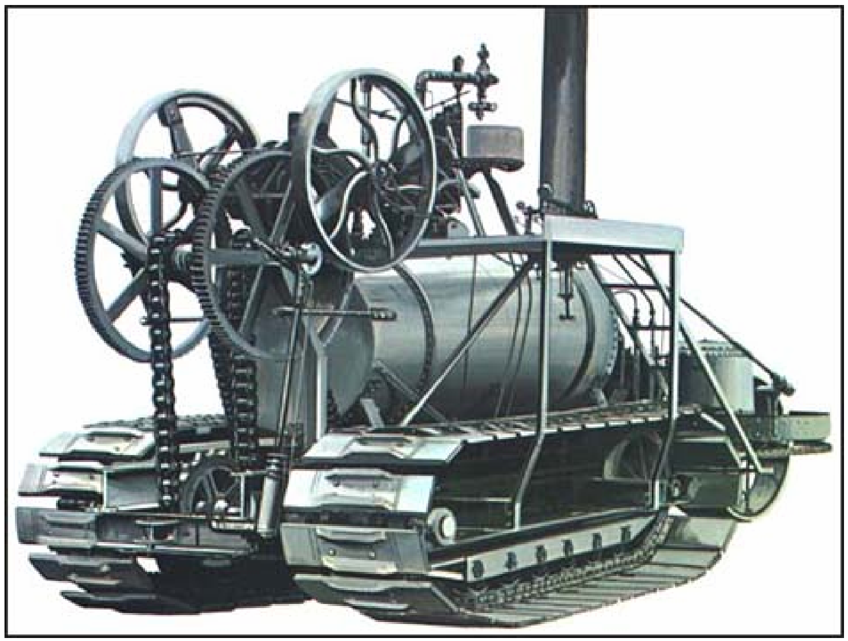


New Weapon Technologies

A British army officer, Colonel Ernest Swinton and the Secretary of the Committee for Imperial Defense, Maurice Hankey, were enthusiastic about the development of a new "armored caterpillar" (landship) for breaking through enemy trench defenses. It was Churchill who sponsored the establishment of the Landships Committee to investigate the potential of constructing what amounted to a new kind of military weapon in the 20th century.

First Attempts

Richard Edgeworth invented the Caterpillar track in 1770. In the Crimean War a small number of steam powered tractors based on this design proved very successful in the muddy terrain.



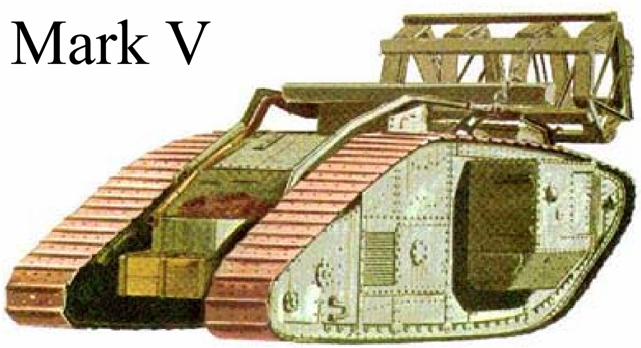
The development of the modern tank remained dormant until the arrival of the internal combustion engine and the right opportunity for extensive use.

Tanks to get the battles moving

- First used by British army at the Somme; initial surprise but attack stalled
- Opportunity for Germans to recover and to develop anti-tank weapons
- First major British tank attack at battle of Cambrai with more than 400 tanks!

Purpose & Developments

Mark V



Tank Production 1916-18

Year	UK	France	Germany	Italy	USA
1916	150	-	-	-	-
1917	1,277	800	-	-	-
1918	1,391	4,000	20	6	84

New Weapons at Air

Air Power Use and Direction

Rapid development of air force leading from observation purpose to plane to plane air battle to bomb raid techniques. First restricted to raids on enemy combatants but rapidly used for air raids on industry, towns, villages, and civilians paving the way for the air raid techniques in World War II and after.

Zeppelins

In the early part of the war Zeppelins were used for bombing raids. A Zeppelin bombed Liege in Belgium on 6th August, 1914 but was forced to land after encountering artillery fire. Three more Zeppelins were destroyed by ground forces over the next two weeks. Although easy to hit, the Germans continued to use them on attacks on France.

In January 1915, two Zeppelin navel airships 190 meters long, flew over the east coast of England and bombed great Yarmouth and King's Lynn. The first Zeppelin raid on London took place on 31st May 1915. The raid killed 28 people and injured 60 more.

1915 tear gas
1915 Chlorgas
1916 Phosgen
1916 Senfgas
1916 Grünkreuz
1917 Blaukreuz
1917 Gelbkreuz

125,000 tons of gas

Lance Sergeant Elmer Cotton, described the effects of chlorine gas in 1915.

It produces a flooding of the lungs - it is an equivalent death to drowning only on dry land. The effects are these - a splitting headache and terrific thirst (to drink water is instant death), a knife edge of pain in the lungs and the coughing up of a greenish froth off the stomach and the lungs, ending finally in insensibility and death. The color of the skin from white turns a greenish black and yellow, the color protrudes and the eyes assume a glassy stare. It is a fiendish death to die.

Gas War

1st use of gas in 1915 at the second battle of Ypres

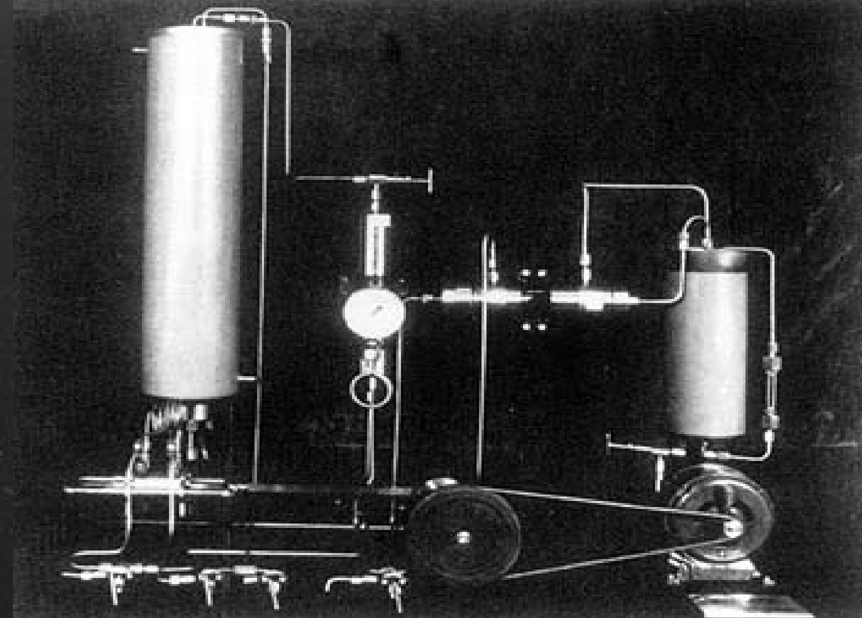
5000 dead 15000 wounded, 2000 permanent blind

long term damages, e.g. cancer

The French were the first to use chemical weapons during the First World War, using tear gas. The first full-scale deployment of chemical warfare agents was during the Second Battle of Ypres, April 22, 1915, when the Germans attacked Entente troops with chlorine gas. Deaths were light, though causalities relatively heavy. A total 50,965 tons of pulmonary, lachrymatory, and vesicant agents were deployed by both sides of the conflict, including chlorine, phosgene and mustard gas.

Gas Victims

Nation	Gas casualties Fatal	Non-fatal
Russia	50,000	400,000
Germany	10,000	190,000
France	8,000	182,000
Britain	8,000	181,000
Austria-Hungary	3,000	97,000
USA	1,500	71,500
Italy	4,500	55,000
Total	85,000	1,176,500

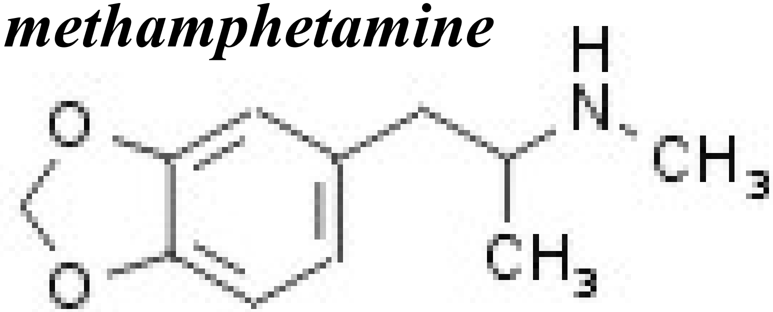


1906: Professor for Physical-Chemistry
University Karlsruhe
1911: Director , Kaiser Wilhelm Institute
for Physical-Chemistry, Berlin
1918: Nobel Prize in Chemistry
For development of Haber Bosch method
(extracting atmospheric Nitrogen and
converting it to Ammonia - fertilizer
1933: Resignation from his post as
KWI director and emigration
to Cambridge, UK; died 1934.

Fritz Haber

One of the leading physical-chemists of his time

3,4-methylenedioxy-methamphetamine



In 1981 as a young undergraduate Haber presumably synthesized first *3,4-methylenedioxy-methamphetamine* (MDMA, called now "Ecstasy")

Fritz Haber has rightfully been called "the greatest authority in the world on the relations between scientific research and industry."

Fritz Haber, the embodiment of a Prussian, was serving his state under any conditions, unquestionably and uncritically accepting the State's wisdom. He served his beloved country in many ways.

Haber's institute worked on numerous wartime concerns including the problem of keeping motors running. He showed that xylene and the solvent naptha were good substitutes for toluene as an antifreeze in benzene motor fuel. Since xylene and naptha were available in Germany and toluene was not, Haber's contributions helped to keep German machinery running and aided in sustaining their war effort for four years.

Haber also served his country in the most basic sense with his process of ammonia synthesis. Not only was ammonia used as a raw material in the production of fertilizers, it was also (and still is, for that matter) absolutely essential in the production of nitric acid. Nitric acid is a raw material for the production of chemical high explosives and other ammunition necessary for the war. Having helped to make Germany independent of Chile and other countries for necessary materials, Haber perhaps served his country in the greatest capacity. Without his process, Germany would never have had a chance to win the war.

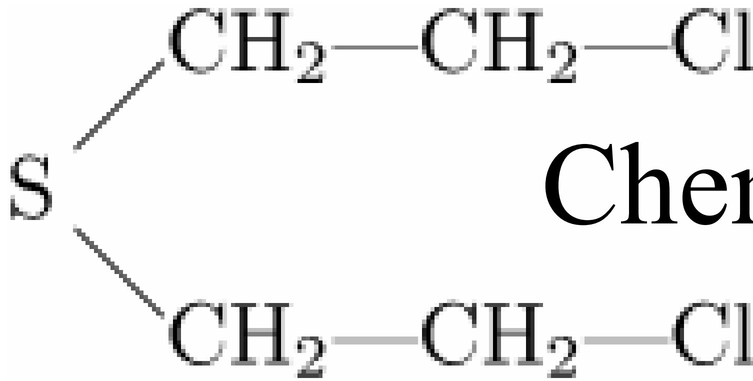
Another contribution Haber made to Germany's war effort was in the development of chemical warfare. With strong purpose and great energy he became involved in the production of protective chemical devices for troops and directed the first gas attacks against enemy troops. Haber is often referred to as the father of modern chemical warfare as he organized and directed the first large scale release of chlorine gas at Ypres, France on April 22, 1915.

From the competition of chemists to the competitions of war industries

Germany
Fritz Haber
KWI Berlin
Chlorine gas
Nobel Prize 1918

France
Victor Grignard
University of Nancy
Mustard & Phosgene gas
Nobel Prize 1912

Phosgene was first used as a weapon by the French, under the direction of French chemist Victor Grignard in 1915. Later, the Germans, under the direction of German chemist Fritz Haber added small quantities of it to chlorine to increase the latter's toxicity. Soon after, use of pure phosgene was begun. Phosgene was responsible for most of the about 100,000 gas-caused deaths during the war



Chemical Weapons

Mustard gas is a strong skin poison. The exposure develops within hours into deep, itching or burning blisters wherever the mustard contacted the skin; the eyes (if exposed) become sore and the eyelids swollen, possibly leading to blindness. At very high concentrations, if inhaled, it causes bleeding and blistering within the respiratory system. Blister agent exposure over more than 50% body surface area is usually fatal. Mustard gas is also chemical reactive with DNA of exposed cells. This leads to either immediate cellular death or, as recent research has found, cancer. Mustard gas is not very soluble in water but is very soluble in fat, contributing to its rapid absorption into the skin.

The Ethical Conflict !

"A scientist belongs to his country in times of war and to all mankind in times of peace." (Fritz Haber)

Clara Immerwahr-Haber

was the first women who attained a PhD in Chemistry (Breslau, 1900). She believed that science should be used for constructive purposes, not for weapons of mass destruction. Fritz Haber tried to keep Clara in the dark about his work on poison gas. During the night after the Gas attack in Ypres with ~5000 dead and ~2000 blinded she committed suicide.

The Kaiser Wilhelm Institute for Physical Chemistry, Berlin

From applied research to war research

The beginning of a modern day weapon laboratory, volunteered for weapon research in 1914 with the start of WW-I, 25 years later it was ordered to weapon research in 1939 with the begin of WW-II.

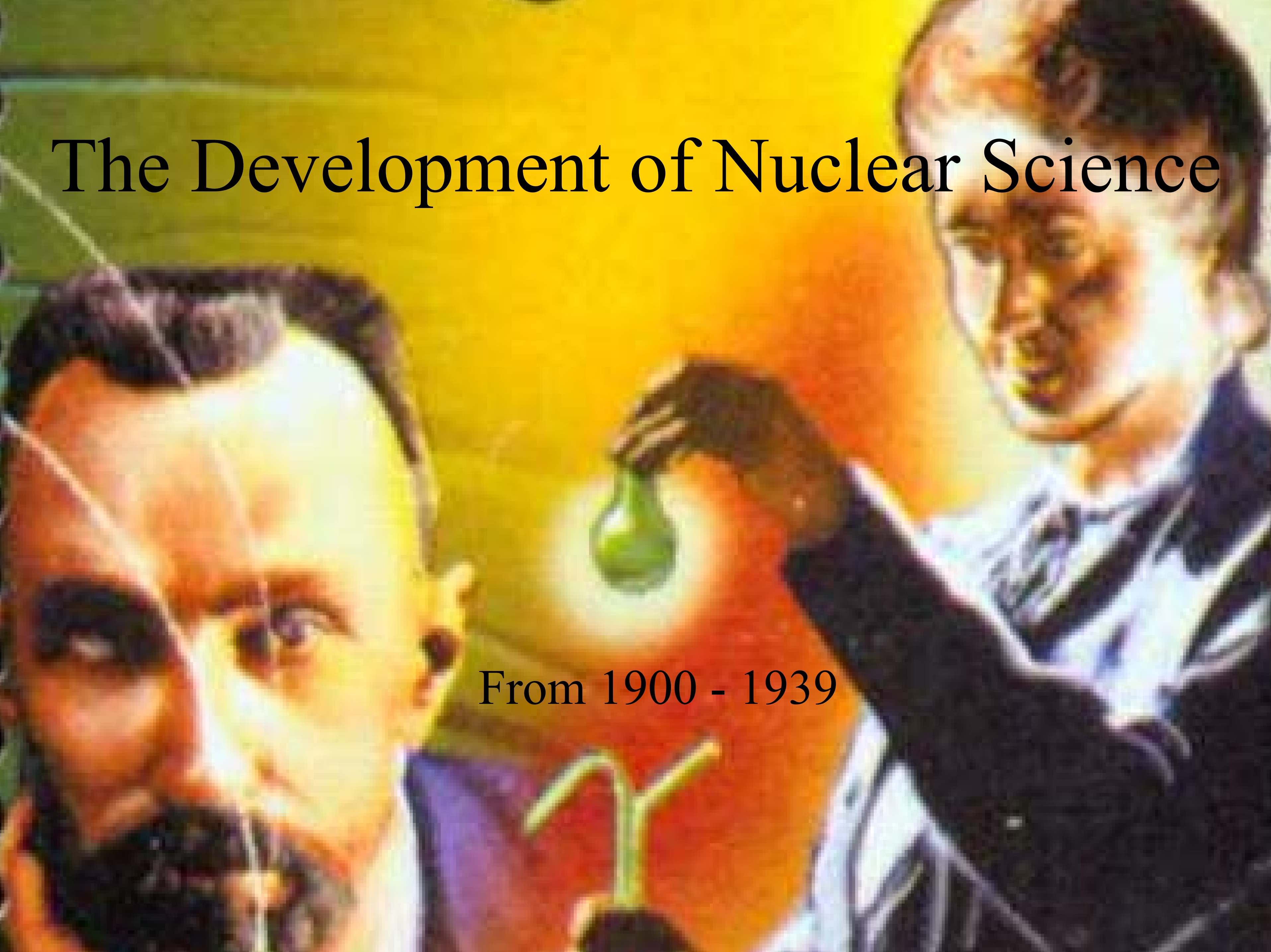
War

The Great War generated a new mind set for the 20th Century

Country	Dead	Wounded	Prisoner
Great Britain	947,000	2,122,000	192,000
France	1,385,000	3,044,000	446,000
Russia	1,700,000	4,950,000	2,500.000
Italy	460,000	947.000	530,000
United States	115,000	206,000	4.500
Germany	1,808,000	4,247,000	618,000
Austria- Hungary	1,200,000	3,620,000	2,200,000
Turkey	325,000	400,000	NA

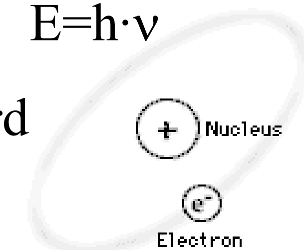
The Development of Nuclear Science

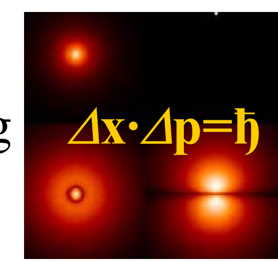
From 1900 - 1939



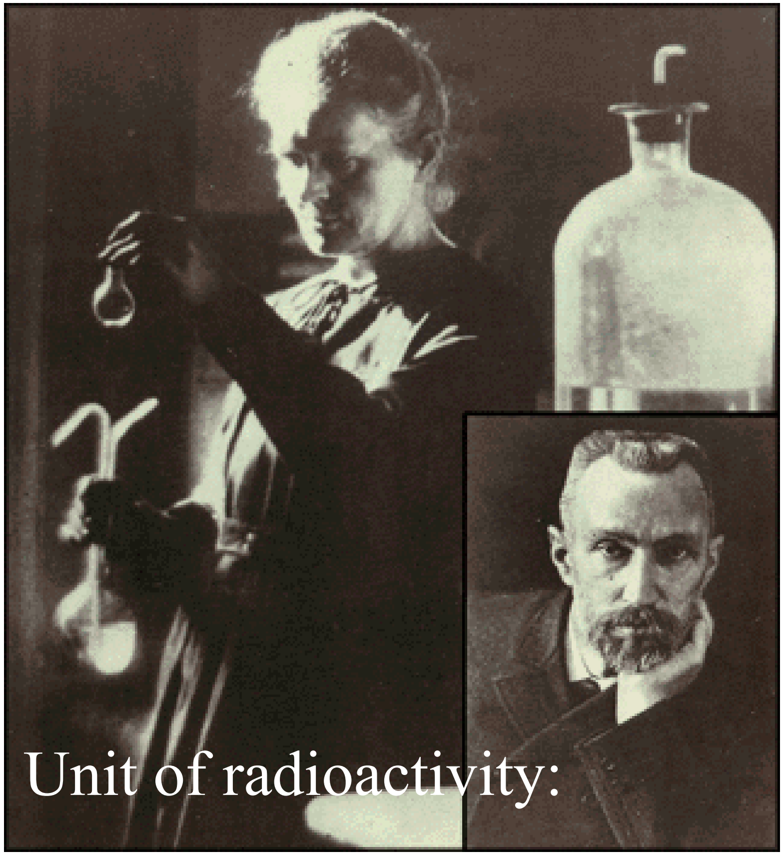
The Development of Scientific Thought in the 20^{th} Century

Discovery & study of radioactivity	1898	Marie &.Pierre Curie	
Introduction of quantum concept	1900	Max Planck	h
Theory of special relativity	1905	Albert Einstein	$E=m \cdot c^2$
Quantization of light (photoelectric effect)	1905	Albert Einstein	$E=h \cdot \nu$
Discovery of atomic nucleus	1911	Ernest Rutherford	
Interpretation of atom structure	1913	Nils Bohr	
Particle waves	1924	Louis de Broglie	
Wave mechanics	1925	Erwin Schrödinger	
Uncertainty principle	1927	Werner Heisenberg	
Discovery of Neutron	1932	James Chadwick	
Artificial Radioactivity (Reactions)	1934	Frederic Joliot & Irene Curie	
Discovery of fission	1938	Otto Hahn, Fritz Strassmann	
Interpretation of fission	1938	Liese Meitner, Otto Frisch	
Prediction of thermonuclear fusion	1939	C.F. v. Weizsäcker, H. Bethe	





The new radiating material



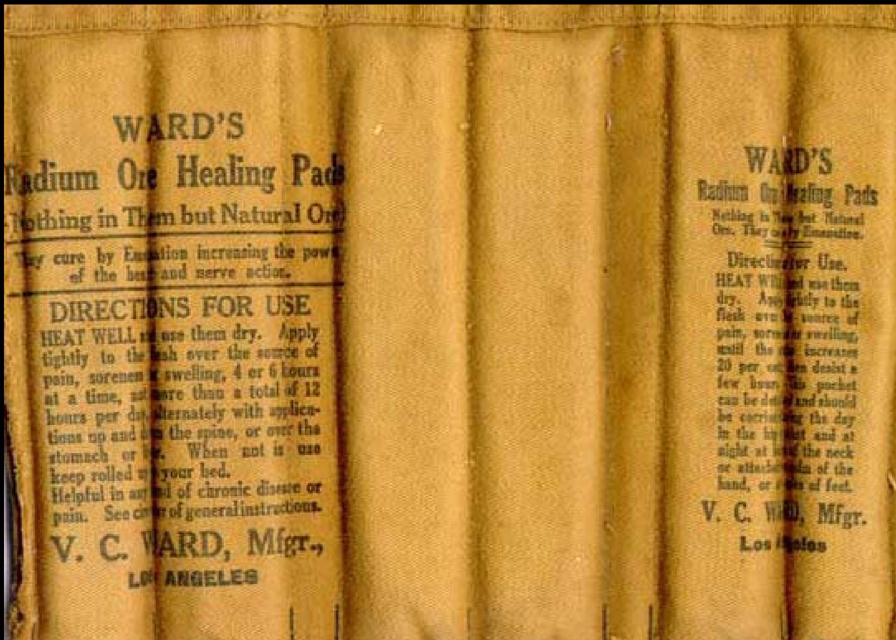
Radioactive material such as Uranium - first discovered by Henri Becquerel – was studied extensively by Marie and Pierre Curie. They discovered other natural radioactive elements such as Radium and Polonium.

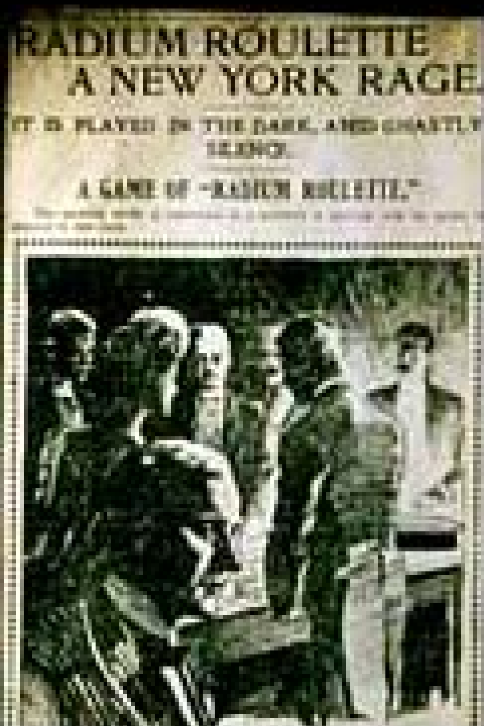
Nobel Prize 1903 and 1911!

Unit of radioactivity:

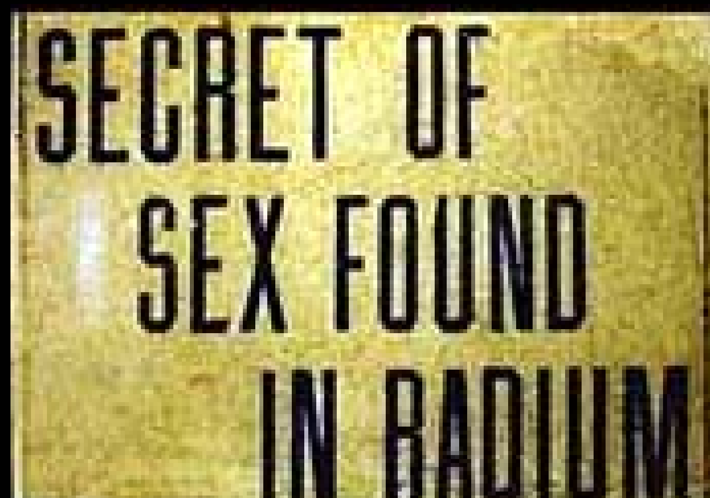
The activity of 1g Ra = 1Ci = $3.7 \cdot 10^{10}$ decays/s   1Bq = 1 decay/s

Discovery triggered a unbounded enthusiasm and led to a large number of medical and industrial applications



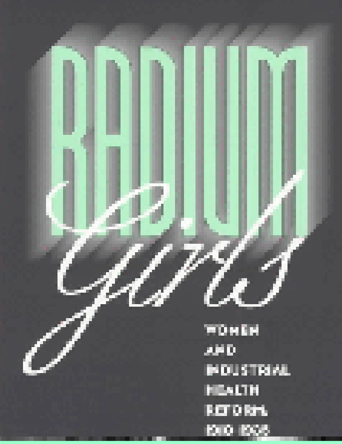


Applications for Radioactivity



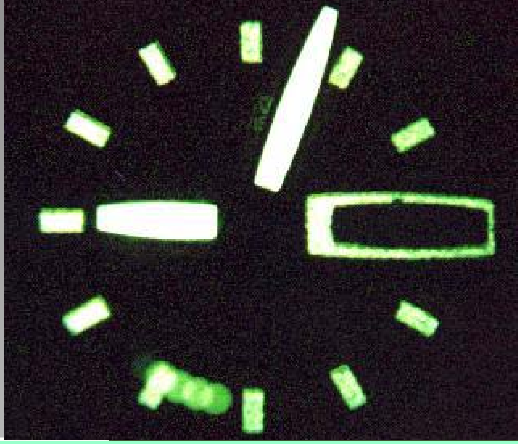
Applications

Popular products included radioactive toothpaste for cleaner teeth and better digestion, face cream to lighten the skin; radioactive hair tonic, suppositories, and radium-laced chocolate bars marketed in Germany as a "rejuvenator." In the U.S, hundreds of thousands of people began drinking bottled water laced with radium, as a general elixir known popularly as "liquid sunshine." As recently as 1952 LIFE magazine wrote about the beneficial effects of inhaling radioactive radon gas in deep mines. As late as 1953, a company in Denver was promoting a radium-based contraceptive jelly.

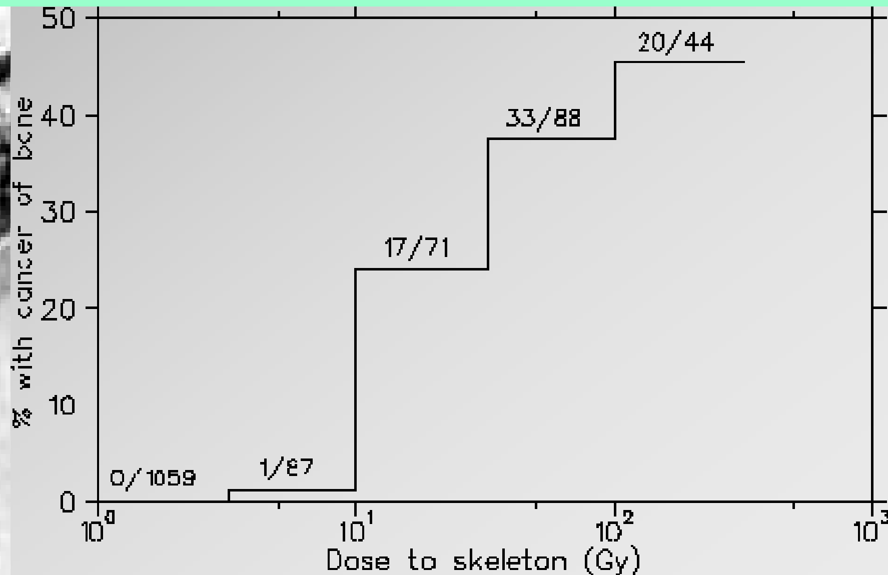


Radium Dials

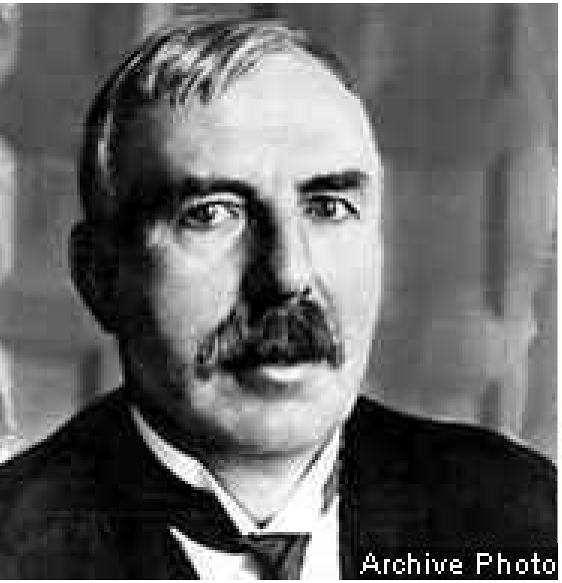
Increase in cancer (tongue – bone) due to extensive radium exposure



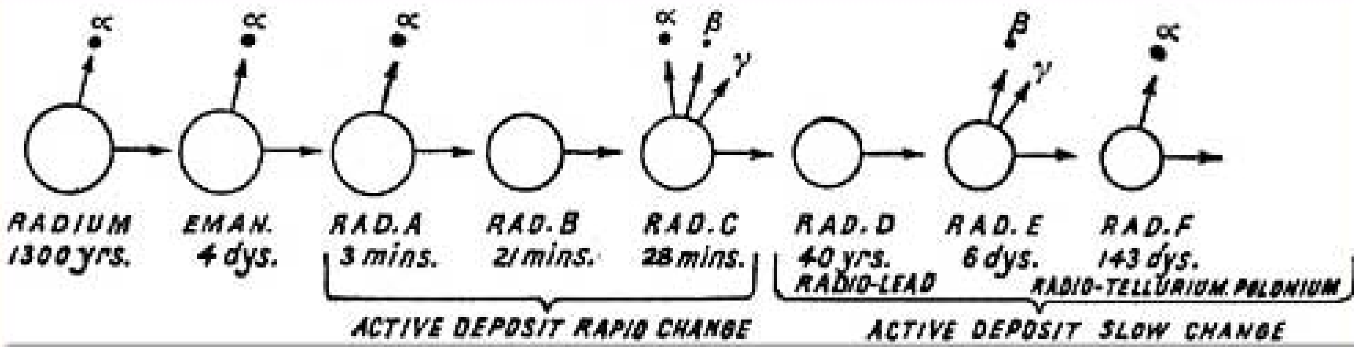
According to a Department of Commerce Information Circular from 1930, the radium paint might contain "from 0.7 to 3 and even 4 milligrams of radium”; this corresponds to a radioactivity level of 0.7 to 4 mCi or 26-150 GBq in modern units.



Explanation of natural radioactivity



Radioactivity comes in three forms α, β, γ

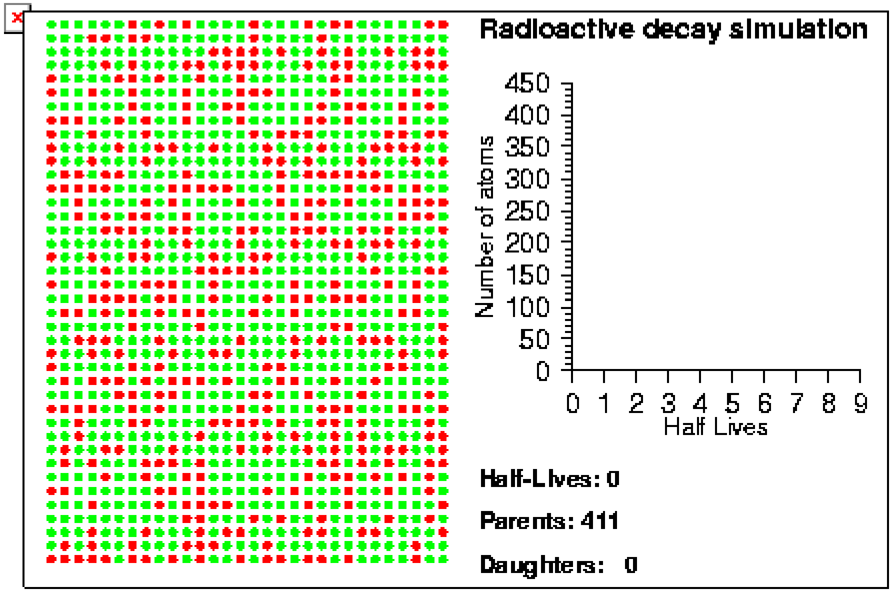


Nobel Prize 1908

Ernest Rutherford's

picture of transmutation. A radium atom emits an alpha particle, turning into "Emanation" (in fact the gas radon). This atom in turn emits a particle to become "Radium A" (now known to be a form of polonium). The chain eventually ends with stable lead. *Philosophical Transactions of the Royal Society of London,* 1905.

The radioactive decay law



exponential decay with time!

$$A_{mother}(t) = A_0 \cdot e^{-\lambda \cdot t}$$

$$A_{daughter}(t) = A_0 \cdot \left(1 - e^{-\lambda \cdot t}\right)$$

λ≡decay constant;
a natural constant
for each radioactive
element.
Half life: $t_{1/2} = \ln 2/\lambda$

1^{st} example: ^{22}Na

^{22}Na has a half-life of 2.6 years, what is the decay constant?
Mass number A=22; (don't confuse with activity *A(t)!*)

$$\boxed{\begin{gathered}\lambda = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{2.6\,y} = 0.27\,y^{-1}: \\ 1\,y = 3.14\cdot 10^{7}\,s \approx \pi\cdot 10^{7}\,s \\ \lambda = \frac{\ln 2}{2.6\cdot 3.14\cdot 10^{7}\,s} = 8.5\cdot 10^{-9}\,s^{-1}\end{gathered}}$$

radioactive decay laws

Activity of radioactive substance *A(t)* is at any time t proportional to number of radioactive particles *N(t)* :

$$A(t) = \lambda \cdot N(t)$$

A ^{22}Na source has an activity of 1 μCi = 10^{-6} Ci, how many ^{22}Na isotopes are contained in the source?
(1 Ci = $3.7 \cdot 10^{10}$ decays/s)

$$\boxed{N = \frac{A}{\lambda} = \frac{10^{-6}\, Ci}{8.5 \cdot 10^{-9}\, s^{-1}} = \frac{10^{-6} \cdot 3.7 \cdot 10^{10}\, s^{-1}}{8.5 \cdot 10^{-9}\, s^{-1}} = 4.36 \cdot 10^{12}}$$

How many grams of ^{22}Na are in the source?

A gram of isotope with mass number A contains N_A isotopes

$N_A \equiv$ Avogadro's Number = $6.023 \cdot 10^{23}$

⇨ 22g of ^{22}Na contains $6.023 \cdot 10^{23}$ isotopes

$$N = 4.36 \cdot 10^{12} \; particles$$

$$1g = \frac{6.023 \cdot 10^{23}}{22} \; particles$$

$$N = \frac{22 \cdot 4.36 \cdot 10^{12}}{6.023 \cdot 10^{23}} g = 1.59 \cdot 10^{-10} g$$

$$N(t) = N_0 \cdot e^{-\lambda \cdot t}$$

How many particles are in the source after 1 y, 2 y, 20 y?

$$N(t) = 4.36 \cdot 10^{12} \cdot e^{-0.27\,y^{-1} \cdot t} \qquad A(t) = \lambda \cdot N(t) = 8.5 \cdot 10^{-9}\,s^{-1} \cdot N(t)$$

$$N(1y) = 4.36 \cdot 10^{12} \cdot e^{-0.27\,y^{-1} \cdot 1y} = 3.33 \cdot 10^{12} \qquad A(1y) = 28305\,s^{-1} = 0.765\,\mu Ci$$

$$N(2y) = 4.36 \cdot 10^{12} \cdot e^{-0.27\,y^{-1} \cdot 2y} = 2.54 \cdot 10^{12} \qquad A(2y) = 21590\,s^{-1} = 0.58\,\mu Ci$$

$$N(10y) = 4.36 \cdot 10^{12} \cdot e^{-0.27\,y^{-1} \cdot 10y} = 2.93 \cdot 10^{11} \qquad A(10y) = 2490.5\,s^{-1} = 0.067\,\mu Ci$$

Decay in particle number and corresponding activity!

2nd example: Radioactive Decay

Plutonium ^{239}Pu, has a half life of 24,360 years.

1. What is the decay constant?
2. How much of 1kg ^{239}Pu is left after 100 years?

$$\lambda = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{24360y} = 2.85 \cdot 10^{-5} y^{-1}$$

$$N_{^{239}Pu}(t) = N_0 \cdot e^{-\lambda \cdot t} \Rightarrow N_{^{239}Pu}(100y) = 1kg \cdot e^{-2.85 \cdot 10^{-5} y^{-1} \cdot 100y}$$

$$N_{^{239}Pu}(100y) = 0.9972kg$$

$$N_{^{239}Pu}(1{,}000y) = 0.9719kg$$

$$N_{^{239}Pu}(10{,}000y) = 0.7520kg$$

$$N_{^{239}Pu}(24{,}360y) = 0.5kg$$

$$N_{^{239}Pu}(100{,}000y) = 0.0578kg$$

The first step: $E=m\cdot c^2$

"It followed from the special theory of relativity that mass and energy are both but different manifestations of the same thing - a somewhat unfamiliar conception for the average mind. Furthermore, the equation E is equal to m c-squared, in which energy is put equal to mass, multiplied by the square of the velocity of light, showed that very small amounts of mass may be converted into a very large amount of energy and vice versa. The mass and energy were in fact equivalent, according to the formula mentioned before. This was demonstrated by Cockcroft and Walton in 1932, experimentally."

Albert Einstein

Example: Mass-Energy

$$E = mc^2 \qquad 1\,J = 1\,kg\left(\frac{m}{s}\right)^2 \qquad c = 3\cdot 10^8\ \frac{m}{s}$$

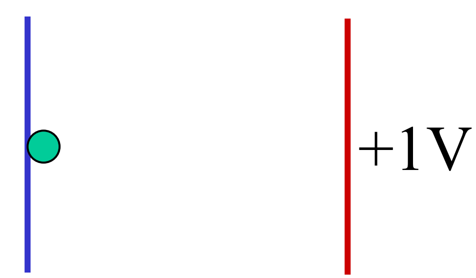
1kg of matter corresponds to an energy of:

$$E = 1kg\cdot\left(3\cdot 10^8\ m/s\right)^2 = 9\cdot 10^{16}\,kg\left(\frac{m}{s}\right)^2 = 9\cdot 10^{16}\,J$$

Definition: 1 ton of TNT = 4.184 x 10^9 joule (J).

1 kg (2.2 lb) of matter converted completely into energy would be equivalent to the energy released by exploding 22 megatons of TNT.

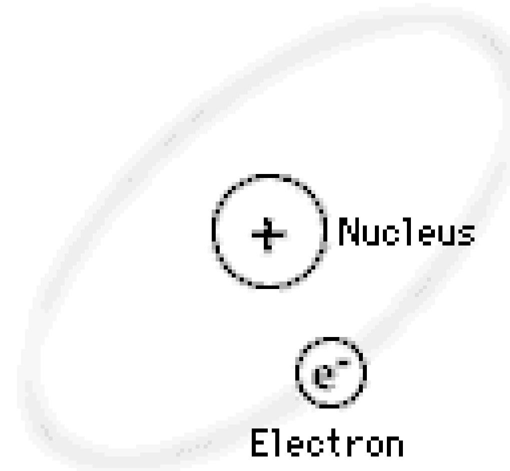
Nuclear physics units: $1\,eV = 1.6\cdot 10^{-19}\,J$



1 electron-volt is the energy one electron picks up if accelerated in an electrical potential of one Volt.

The discovery of the neutron

By 1932 nucleus was thought to consist of protons and electrons which were emitted in β-decay. New Chadwick's experiment revealed a third particle, the neutron



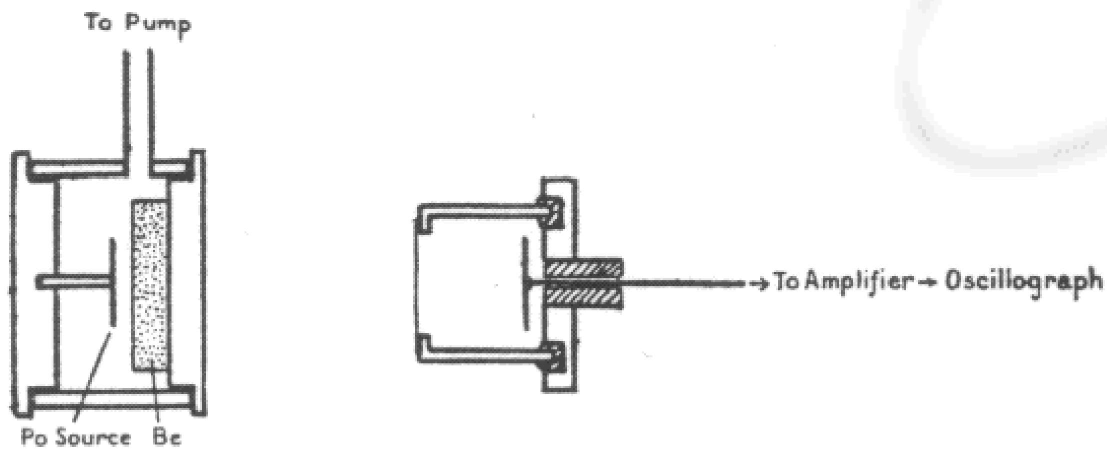
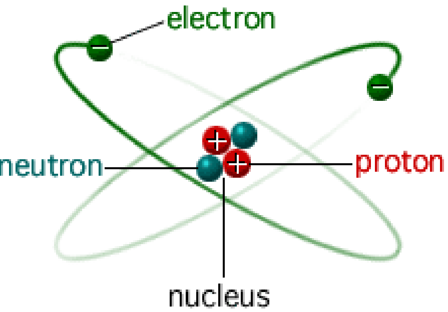


FIG. 1.

Nobel Prize 1935

Strong Polonium source emitted α particles which bombarded Be; radiation was emitted which – based on energy and momentum transfer arguments - could only be neutral particles with similar mass as protons $\Rightarrow$ neutrons: BEGIN OF NUCLEAR PHYSICS!



The model of the nucleus

$A_{\text{mass number}}$ $^{14}_{6}C$

$Z_{\text{atomic number}}$

$N_{\text{neutron number}} = A - Z$

Nucleus with Z protons (p) and N neutrons (n) with a total mass number A=Z+N

Hydrogen: 1 p, 0,1 n $\quad {}^{1}_{1}H_{0} \quad {}^{2}_{1}D_{1}$

Helium: 2 p, 1,2 n $\quad {}^{3}_{2}He_{1} \quad {}^{4}_{2}He_{2}$

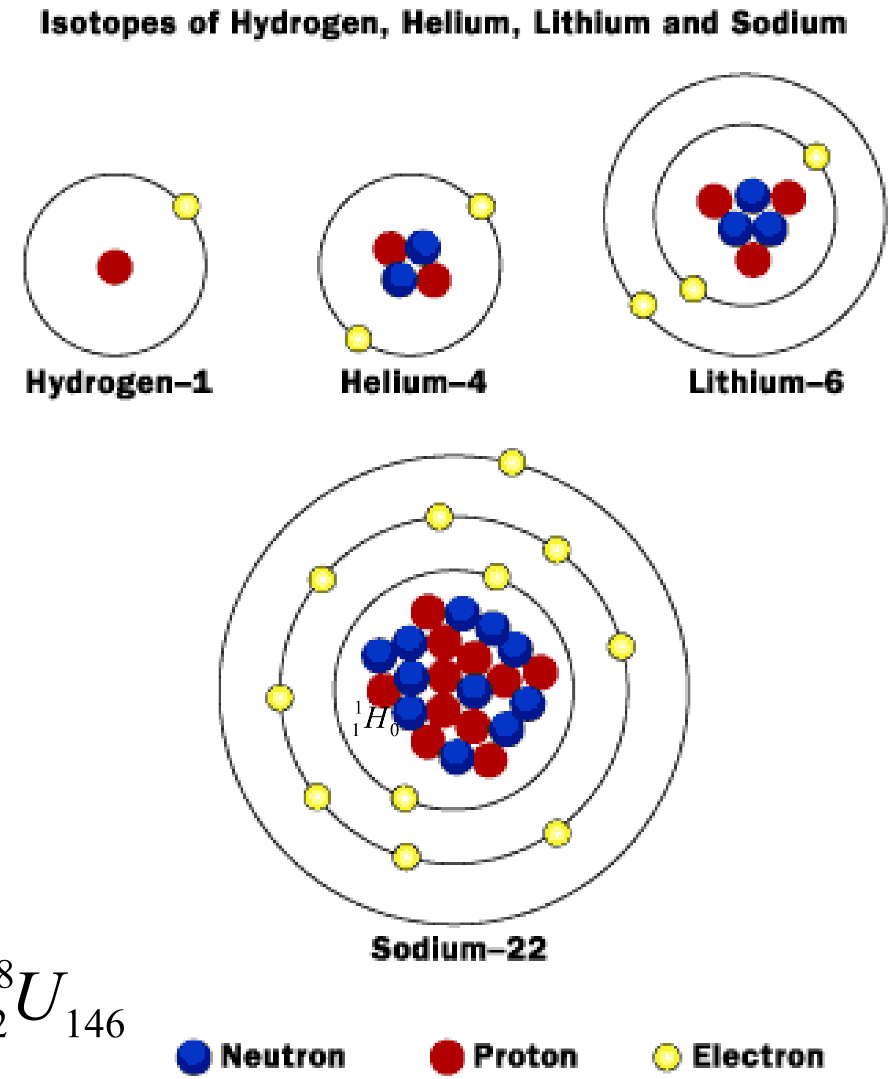
Lithium: 3 p, 3,4 n $\quad {}^{6}_{3}Li_{3} \quad {}^{7}_{3}Li_{4}$

Carbon: 6 p, 6,7 n $\quad {}^{12}_{6}C_{6} \quad {}^{13}_{6}C_{7}$

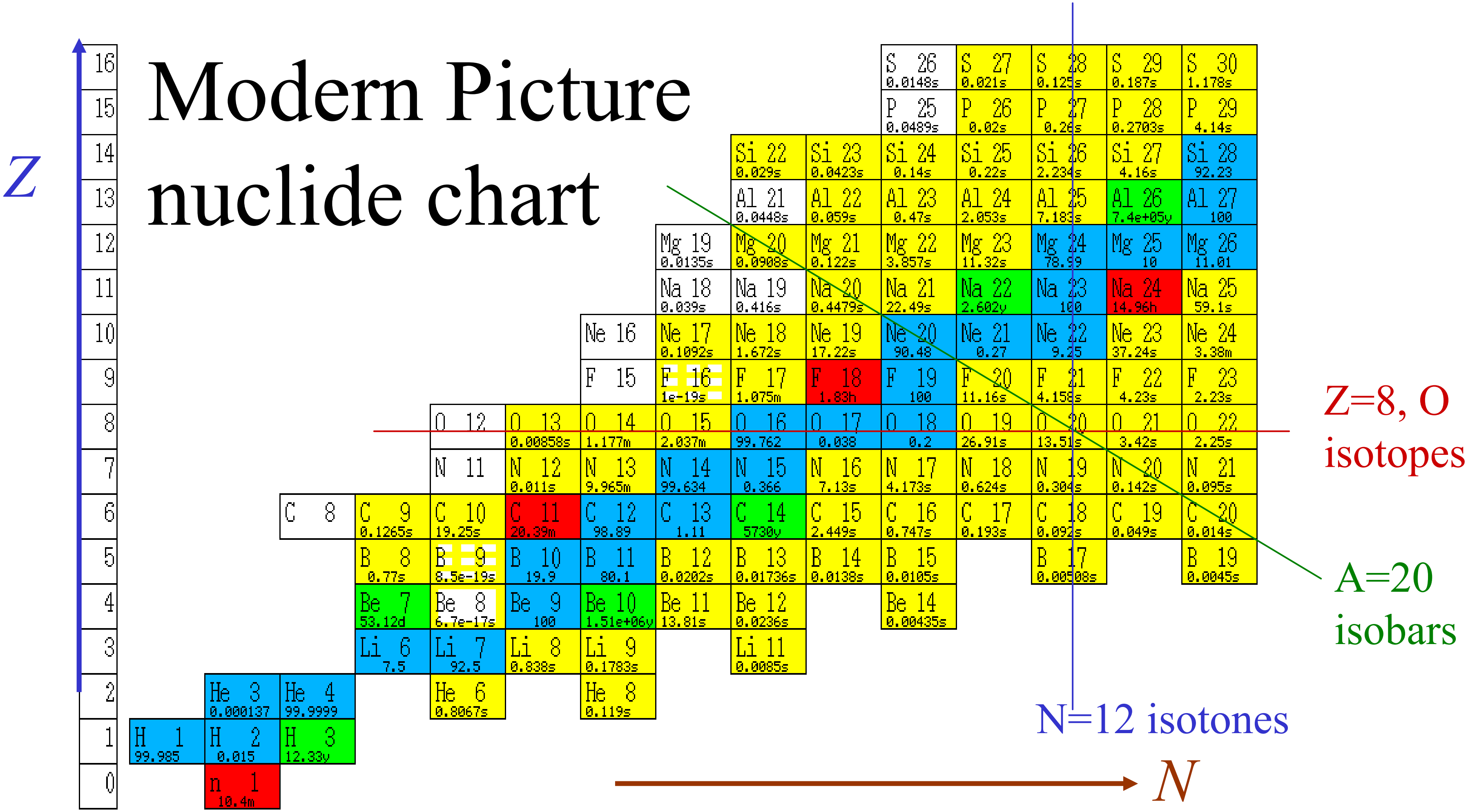
…

…

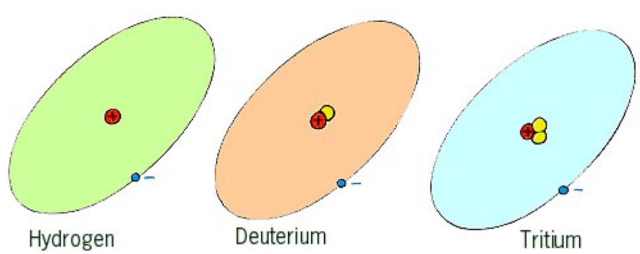
Uranium: 92 p, 143,146 n $\quad {}^{235}_{92}U_{143} \quad {}^{238}_{92}U_{146}$



Modern Picture nuclide chart



hydrogen isotopes: Z=1



Isotopes: Z=constant, N varies!

Isotones: N=constant, Z varies!

Isobars: A=constant, Z,N varies!

Energy in Nuclei

According to Einstein's formula each nucleus with certain mass ***m*** stores energy $E=mc^2$

Proton	$m_p = 1.007596 \cdot 1.66\cdot10^{-24}$ g	$= 1.672\cdot10^{-24}$ g
Neutron	$m_n = 1.008486 \cdot 1.66\cdot10^{-24}$ g	$= 1.674\cdot10^{-24}$ g
Carbon	$m_{^{12}C} = 12.00000 \cdot 1.66\cdot10^{-24}$ g	$= 1.992\cdot10^{-23}$ g
Uranium	$m_{^{238}U} = 238.050783 \cdot 1.66\cdot10^{-24}$ g	$= 3.952\cdot10^{-22}$ g

Binding energy B of nucleus

$$B = (Z \cdot m_p + N \cdot m_n - M) \cdot c^2$$

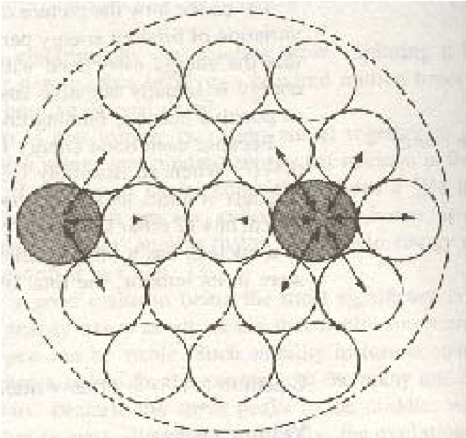
$B(^{12}C) = 1.47 \cdot 10^{-11}$ J; $B/A = 1.23 \cdot 10^{-12}$ J

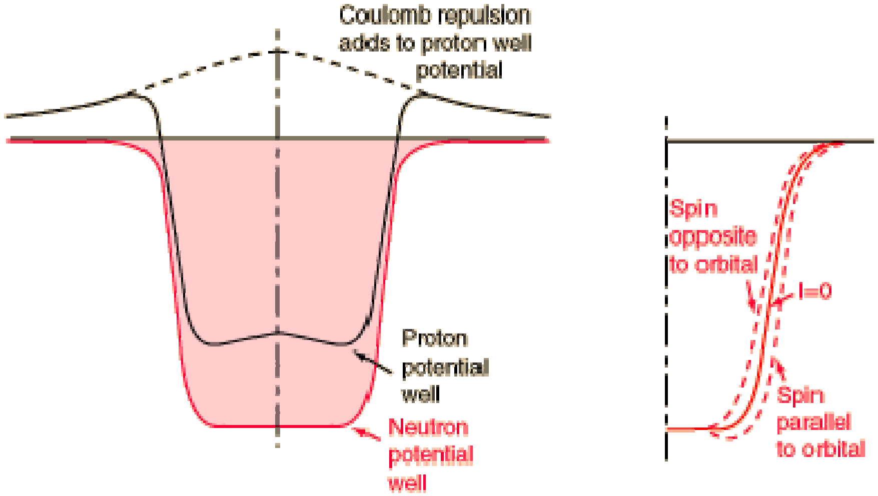
$B(^{238}U) = 2.64 \cdot 10^{-10}$ J; $B/A = 1.21 \cdot 10^{-12}$ J

1 amu=1/12($M^{12}C$)=$1.66 \cdot 10^{-24}$ g

Breaking up nuclei into their constituents requires energy

Nuclear Potential





$$B = a_v \cdot A - a_s \cdot A^{2/3} - a_c \cdot Z \cdot (Z-1) \cdot A^{-1/3} - a_{sym} \cdot \frac{(A-2Z)^2}{A} + \delta$$

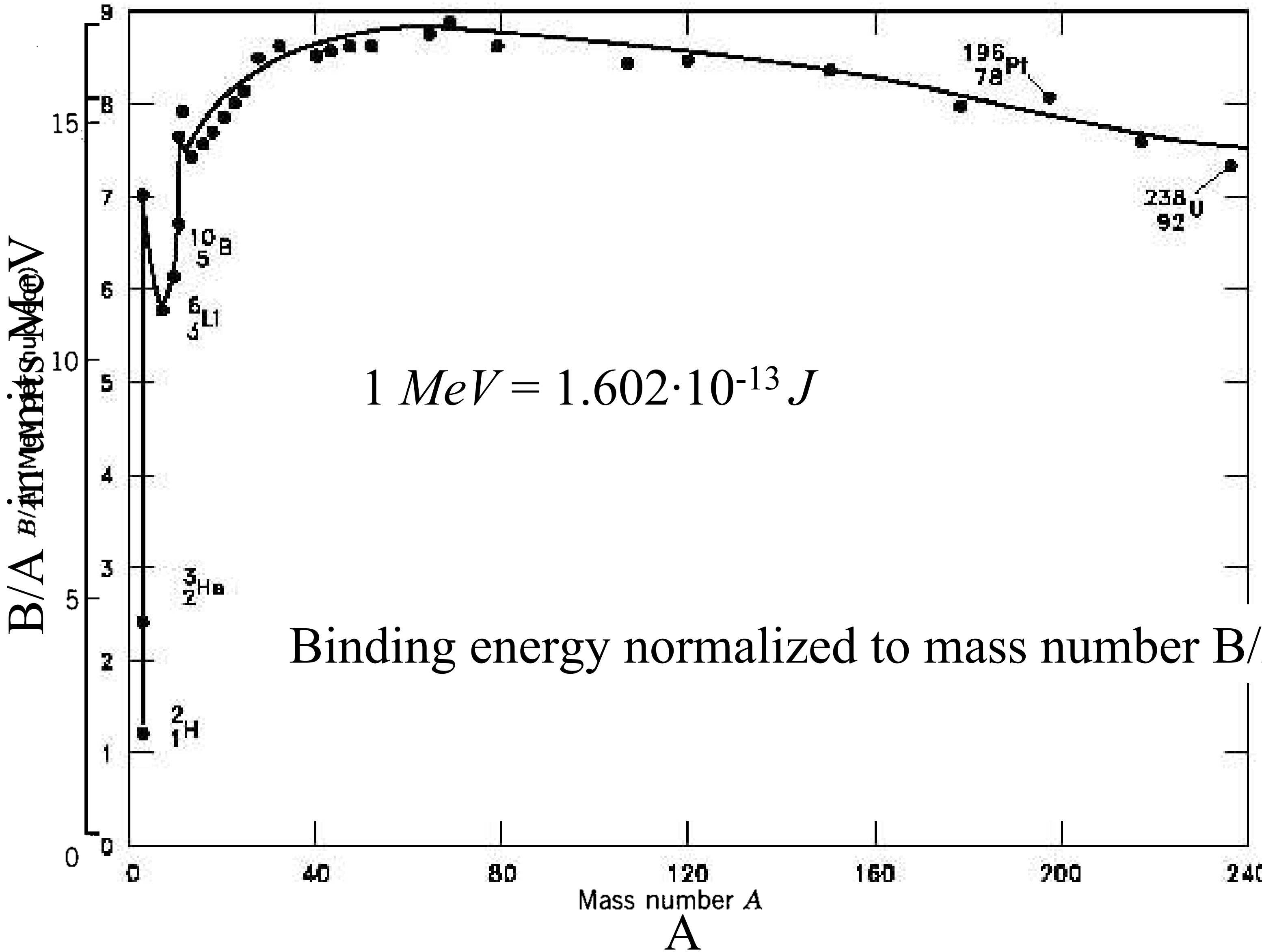
$$\delta = +a_p \cdot A^{-4/3}\ (Z, N\ even);\ \delta = -a_p \cdot A^{-4/3}\ (Z, N\ odd);\ \delta = 0\ (A = Z + N\ odd);$$

$$a_v = 15.5 MeV;\ a_s = 16.8 MeV;\ a_c = 0.72 MeV;\ a_{sym} = 23 MeV;\ a_p = 34 MeV$$

http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/liqdrop.html#c2

$$1\ MeV = 1.602 \cdot 10^{-13}\ J$$

Nuclear Binding Energy



$1\ MeV = 1.602 \cdot 10^{-13}\ J$

Binding energy normalized to mass number B/A

Example: Nuclear Binding Energy

Conversion of nuclei through fusion or fission leads to release of energy!

isotope	B (J)
^{2}H	$3.34131 \cdot 10^{-13}$
^{4}He	$4.53297 \cdot 10^{-12}$
^{12}C	$1.47643 \cdot 10^{-11}$
^{119}Pd	$1.59643 \cdot 10^{-10}$
^{238}U	$2.88631 \cdot 10^{-10}$

$$
{}^{2}_{1}H_{1} + {}^{2}_{1}H_{1} \Rightarrow {}^{4}_{2}He_{2} + Q
$$

$$
Q = B({}^{4}He) - 2 \cdot \left(B({}^{2}H) + B({}^{2}H) \right)
$$

$$
Q = 2 \cdot 3.34131 \cdot 10^{-13} J - 4.53295 \cdot 10^{-12} J = 3.8647 \cdot 10^{-12} J
$$

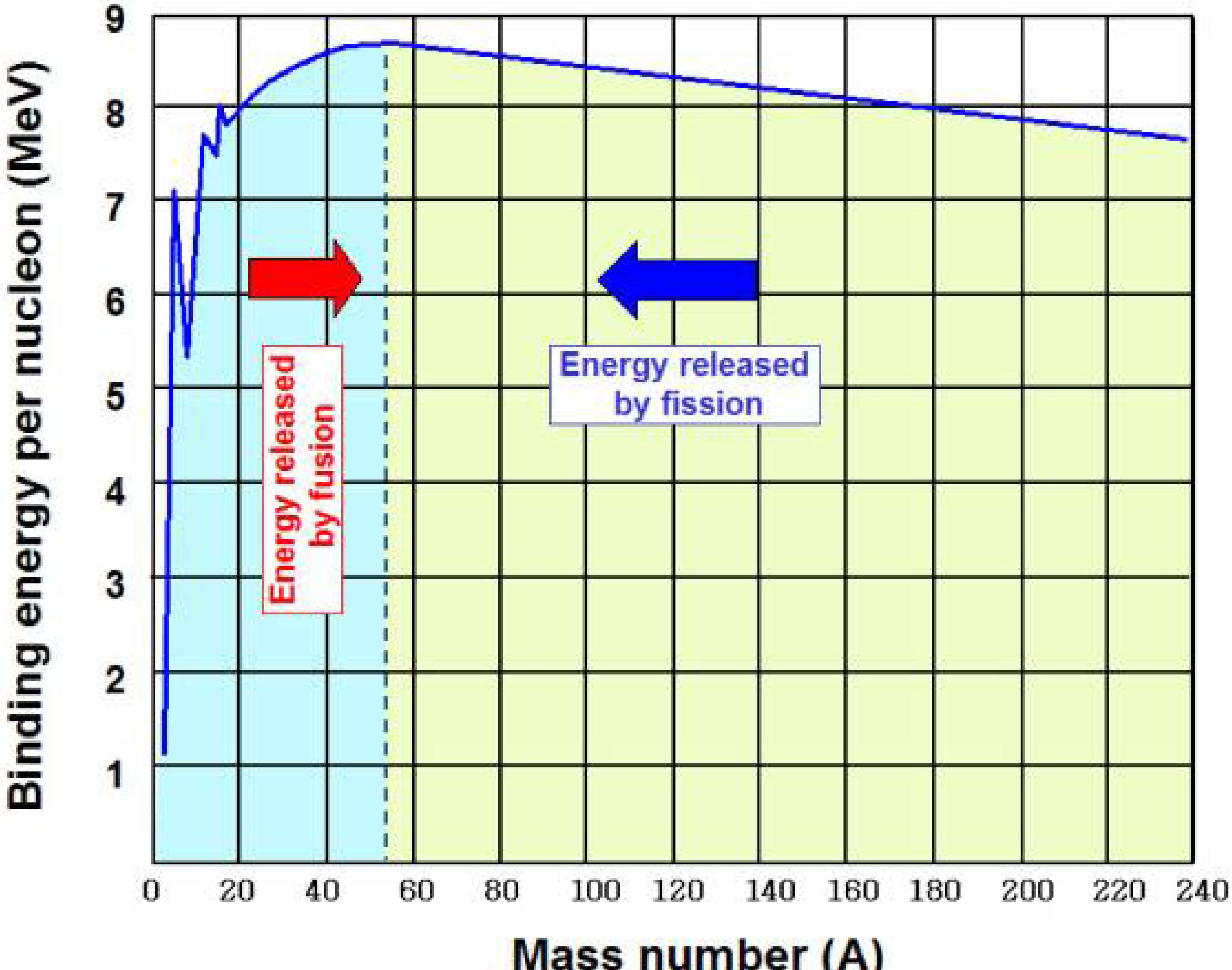
$$
{}^{238}_{92}U_{146} \Rightarrow 2\ {}^{119}_{46}Pd_{73} + Q
$$

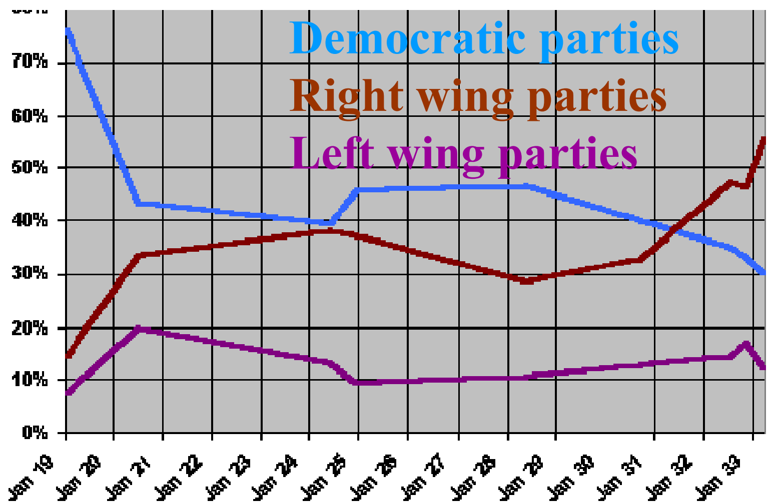
$$
Q = B({}^{119}_{46}Pd_{73}) + B({}^{119}_{46}Pd_{73}) - B({}^{238}_{92}U_{146})
$$

$$
Q = 2.88631 \cdot 10^{-10} J - 2 \cdot 1.59633 \cdot 10^{-10} J = 3.06542 \cdot 10^{-11} J
$$

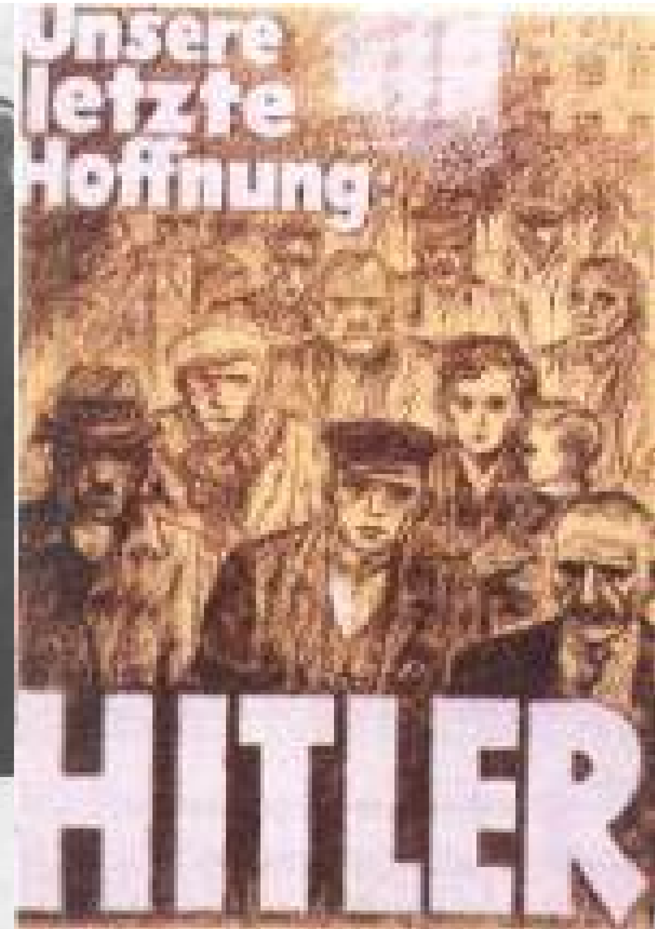
http://ie.lbl.gov/toimass.html
http://nucleardata.nuclear.lu.se/database/masses/
http://www.nndc.bnl.gov/masses/mass.mas03

Nuclear Energy possible through fission and fusion





In January 1933 Hitler was appointed by President Hindenburg as new German Chancellor



-Reichstagsbrand-

27 February 1933

This *Decree of the Reich President for the Protection of the People and State* abrogates the following constitutional protections:

- Free expression of opinion
- Freedom of the press
- Right of assembly and association
- Right to privacy of postal communications
- Protection against unlawful searches & seizures
- Individual property rights
- States' right of self-government

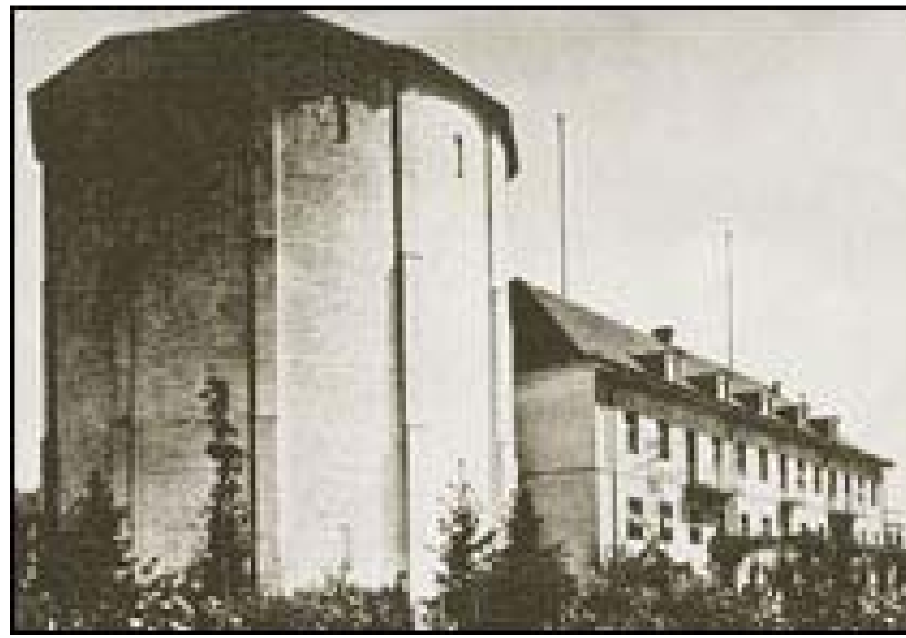
A supplemental decree creates the SA (Storm Troops) and SS (Special Security) Federal police agencies.

The Reichstag building, seat of the German parliament, burns after being set on fire. This enabled Adolf Hitler to seize power under the pretext of protecting the nation from threats to its security. (Photo credit: U.S. National Archives)

Consequences for Science and Academia

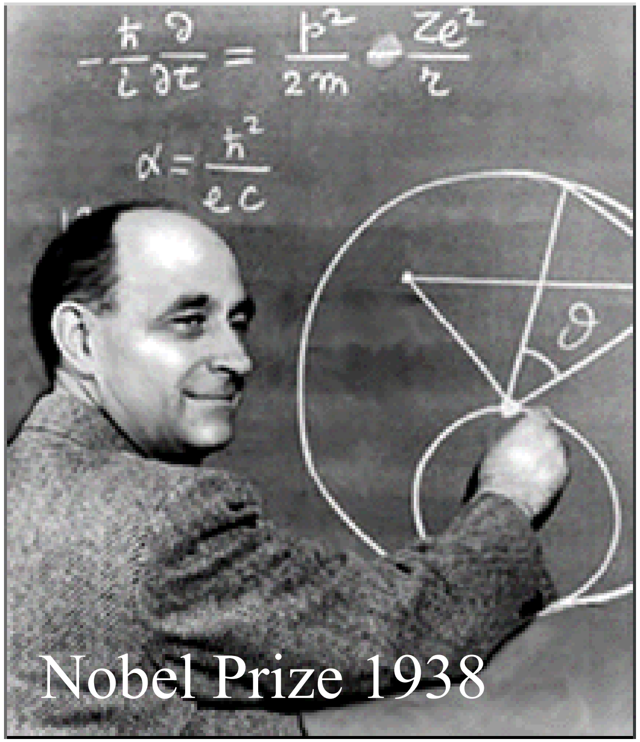
Removal from all Jewish faculty members from their posts (Law of restoration of Career Civil Service 1933).
Many of the leading figures emigrated. Bernhard Rust became Minister of Education took more flexible stand. Jewish scientists were allowed to hold temporary assistant posts, but were facing increasing administrative difficulties.

KWI under Planck tried first to remain independent but got more involved in war related research during WW-II.



KWI for Physics in Berlin with van de Graaff Accelerator tower in front

Nuclear Reactions and Energy Release



Nobel Prize 1938

Frederic Joliot and Irene Curie at Paris had observed the first nuclear reaction. Enrico Fermi showed the existence of neutron induced reactions which produce artificial radioactivity.

Nuclear reactions can produce energy
$Q > 0$ exothermic
or need energy
$Q < 0$ endothermic

$$\boxed{\begin{gathered}\text{A(a,b)B}\\ Q = (m_A + m_a - m_B - m_b)\cdot c^2 \\ Q = B_B + B_b - B_A - B_B\end{gathered}}$$

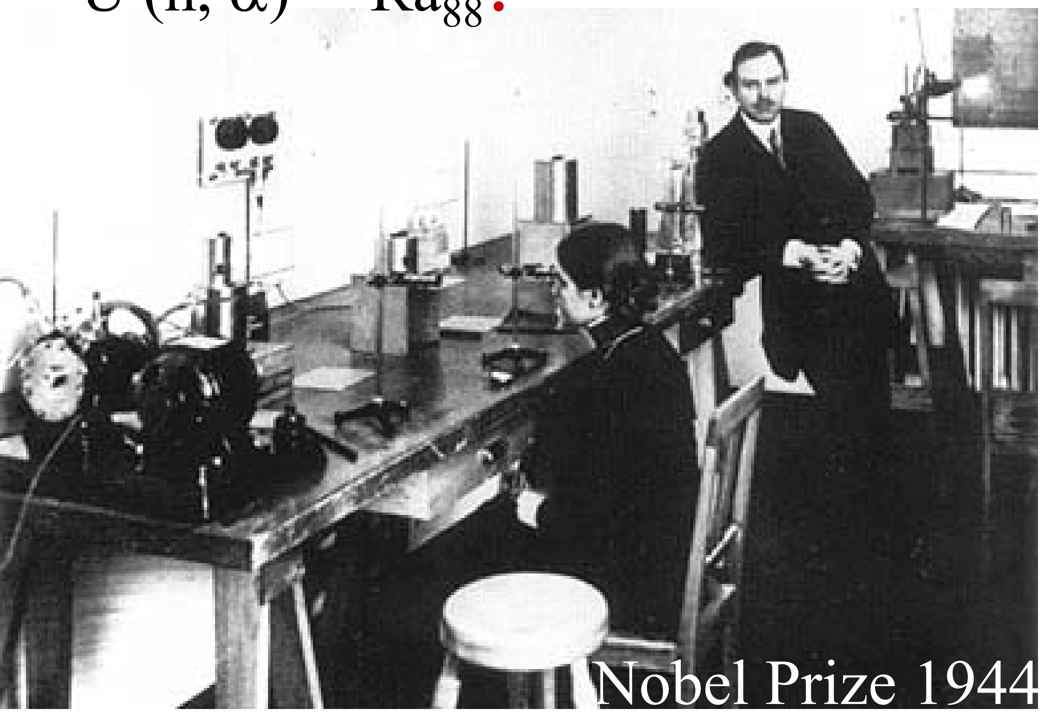
difference of masses in entrance and exit channel determines Q

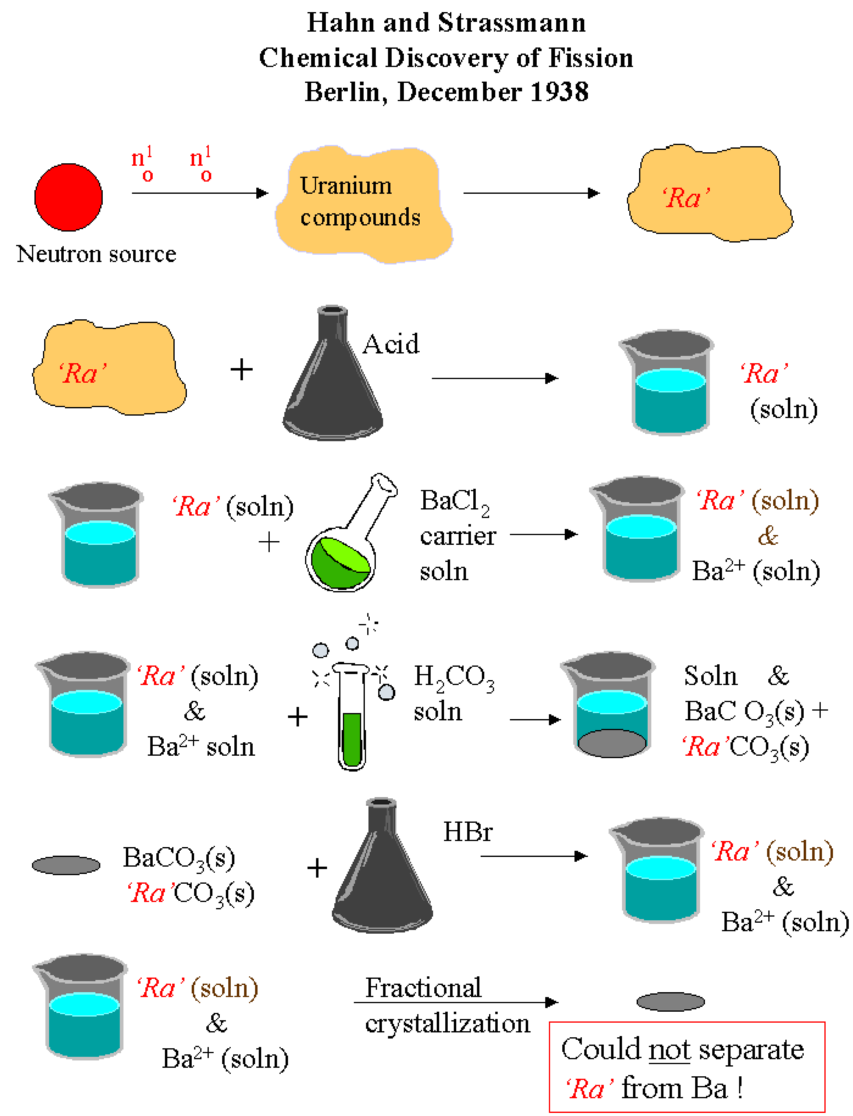
The discovery of fission 1938

Search for transuranium elements Z>92

$^{238}U\ (n, \gamma)\ ^{239}U_{92}\ (\beta^{-})\ ^{239}E_{93}\ (\beta^{-})\ ^{239}E_{94}$

$^{238}U\ (n, \alpha)\ ^{235}Ra_{88}$?





Hahn and Strassmann identified broad variety of elements, they thought those to be near Uranium, e.g. Z=88 Radium

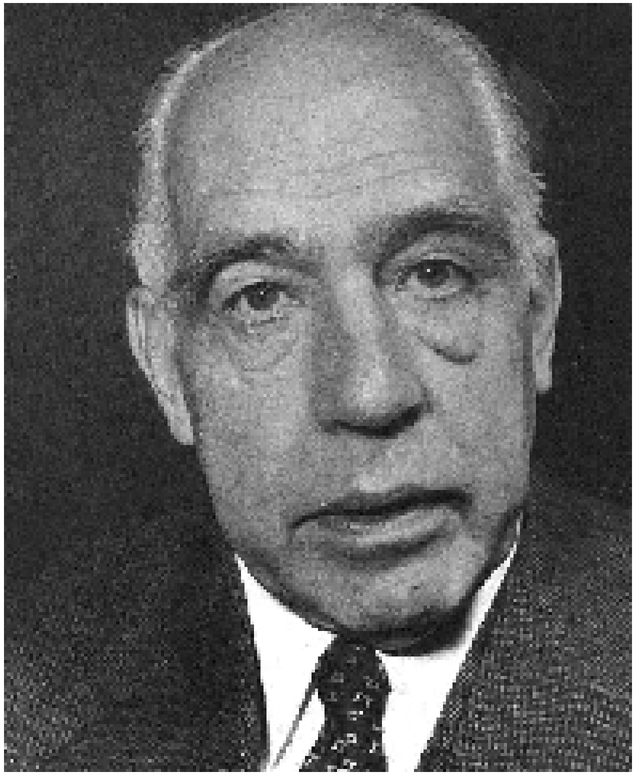
The interpretation of fission I

Hahn and Strassmann repeated the experiment numerous times and were never able to isolate the ‘radium’ from barium. They reported their results as follows: "As chemists, we must actually say the new particles do not behave like radium but, in fact, like barium; as nuclear physicists, we cannot make this conclusion, which is in conflict with all experience in nuclear physics." Hahn, the chemist, was reluctant to go against the ideas of nuclear physicists, despite clear chemical evidence of barium.

Close correspondence with collaborator Lise Meitner who had emigrated to Stockholm in 1938 to Manne Siegbahn.

The Interpretation of Fission II

Now whenever mass disappears energy is created, according to Einstein's formula $E = mc^2$, and... the mass was just equivalent to 200 MeV; it all fitted! Meitner was convinced that the product actually was Barium rather than a homologue. The nightmare of contradictory evidence all fit the explanation that Uranium had fissioned (broke into pieces) rather than form a heavier element. Frisch calculated the energy needed, and Meitner calculated the energy available. The other fragment must be Krypton to conserve atomic number. ${}^{1}_{0}n + {}^{238}_{92}U \rightarrow {}^{137?}_{56}Ba + {}^{84?}_{36}Kr + 18?\ {}^{1}_{0}n$



Niels Bohr

Brought news of fission to the US at the fifth Washington Conference on Theoretical Physics.

Several researchers went back to their labs and confirmed the work and reported back before the conference was over.

Within a few month Bohr and Wheeler predicted the possibility of chain reaction by fission of ^{235}U with similar energy out put as ^{238}U. Problem was to generate ^{235}U, which is a very rare Uranium isotope.

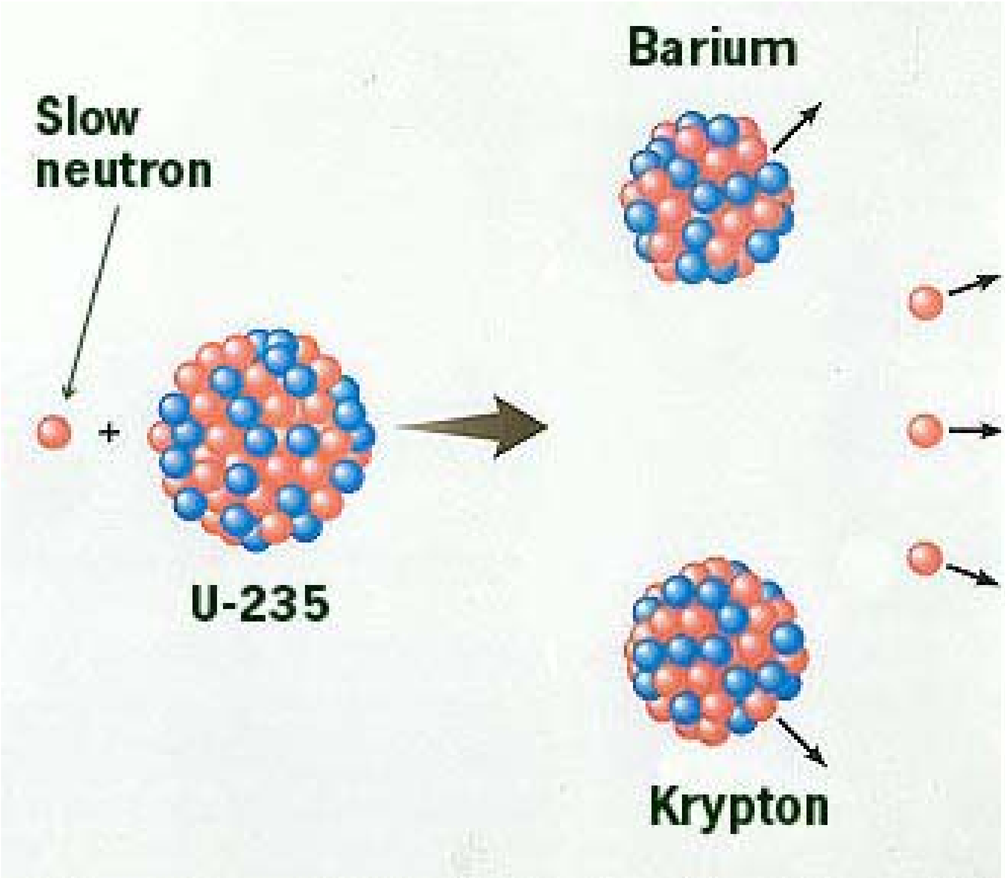
Germany stopped all Uranium exports

Chain Reaction (?)

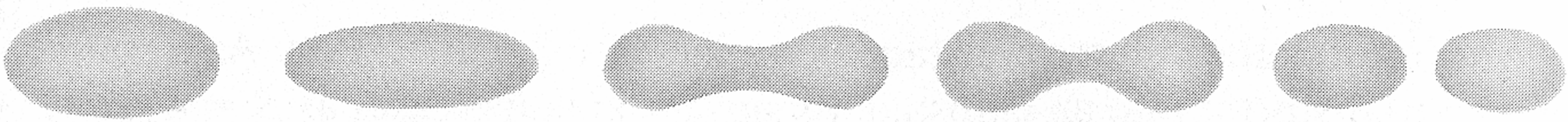
The following is an example of a predicted fission reaction which generates neutrons besides energy.

The two fission products are very radioactive as they have far too many neutrons in their nuclei. The neutrons are ejected and will then trigger subsequent fission processes

$\Rightarrow$ Chain reaction

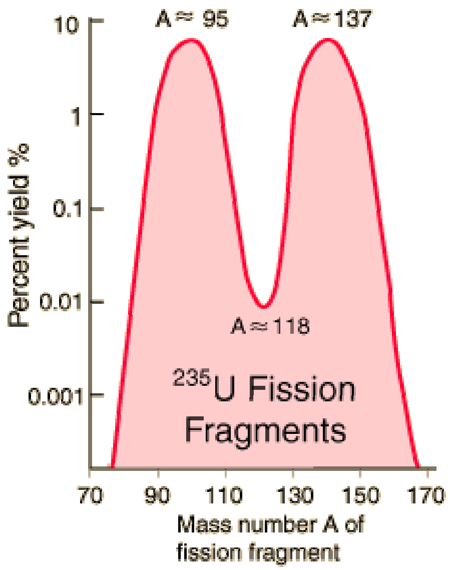


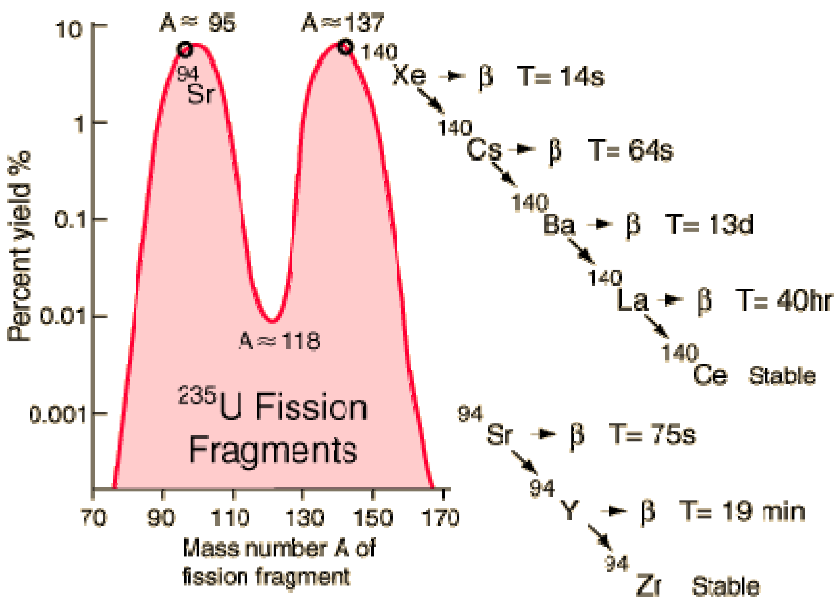
$$^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{142}_{56}Ba + {}^{91}_{36}Kr + 3\,{}^{1}_{0}n$$



Representation of nuclear shapes in fission.

Fission fragments





When ^{235}U undergoes fission, the average of the fragment mass is about 118, but very few fragments near that average are found. It is much more probable to break up into unequal fragments, and the most probable fragment masses are around mass 95 and 137. Most of the fission fragments are radioactive, intense short lived and long-lived radioactive elements are released into the environment.

Energy release in fission

Total energy = energy release/fission · number of fission events

Suppose you have 5 kg of ^{235}U and 10% of it undergoes fission, calculate the total energy release?

$N_A \equiv$ Avogadro's Number = $6.023 \cdot 10^{23}$

A gram of isotope with mass number A contains N_A isotopes

$$235g(^{235}U) \equiv 6.023 \cdot 10^{23} \quad {}^{235}U \; isotopes$$
$$500g(^{235}U) \equiv \frac{500}{235} \cdot 6.023 \cdot 10^{23} = 1.28 \cdot 10^{24} \quad {}^{235}U \; isotopes$$

$$^{235}_{92}U_{143} \Rightarrow {}^{95}_{37}Rb_{58} + {}^{137}_{55}Cs_{82} + Q$$
$$Q = B({}^{95}_{37}Rb_{58}) + B({}^{137}_{55}Cs_{82}) - B({}^{235}_{92}U_{143})$$
$$Q = 803.7\text{MeV} + 1{,}149.3MeV - 1{,}783.8MeV = 169MeV$$
$$Q \approx 200MeV = 200 \cdot 1.6 \cdot 10^{-13} J = 3.2 \cdot 10^{-11} J$$

Total energy release ≈ $4.1 \cdot 10^{13}$ J = $9.8 \cdot 10^{3}$ tons TNT ≈ 10 k-tons TNT

(Definition: 1 ton of TNT = 4.184 x 10^{9} joule (J).)

1939 Begin of World War II

- *Japan Invades China*

Hitler Invades

Poland
France
Belgium
Netherlands
Norway
Danmark
Yugoslavia
Greece

World War II Weapons of Mass Destruction

Concept of *Strategic* ***Air Bombing***
introduced by Sir Hugh Trenchard

W W II
(1939-1945)

1940-41: Battle for Britain
Civilian population targeted

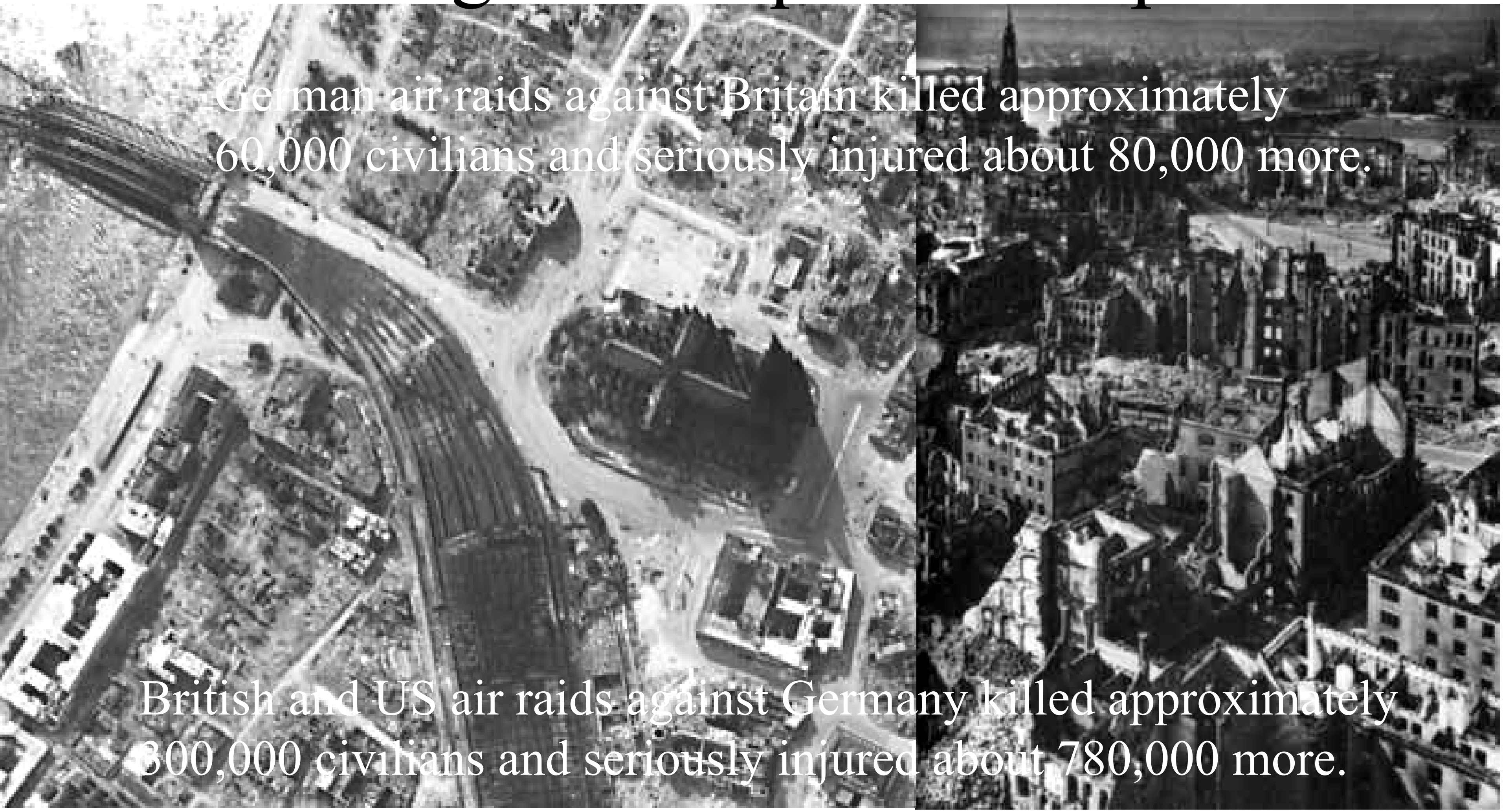
1941-1944: Allied Bombing Campaign:

Incendiary bombs
Carpet bombing
Artificial firestorms

~1000 planes/ several tons of bombs each

Sir Arthur Harris
(Bomber Harris)

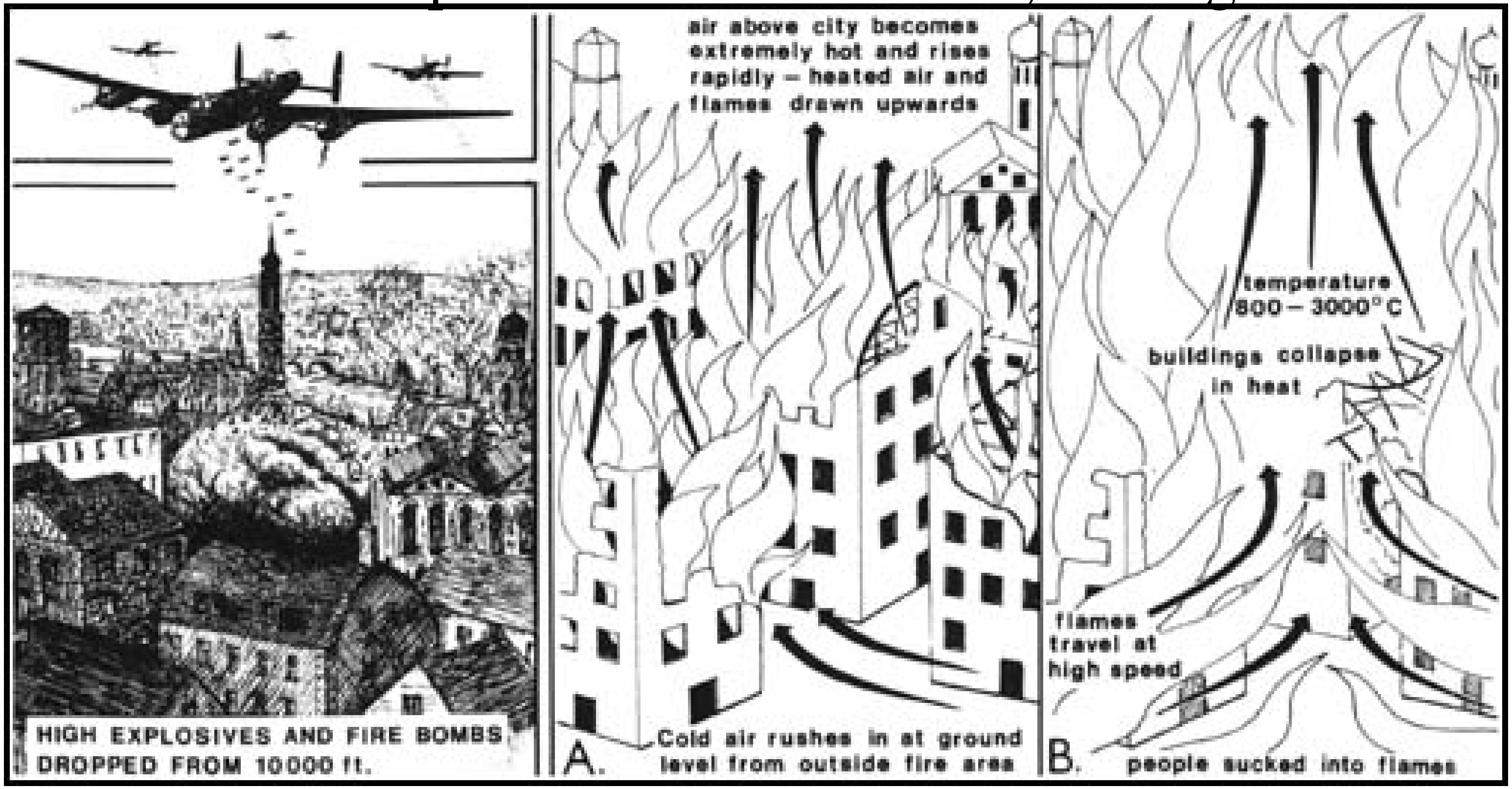
Bombing Technique Developments



Large 500-1000 plane bombing armadas (limited defense)
As well as area bombing techniques and firestorm techniques

Technique

The fire storms developed winds up to 300 mph
and air temperatures estimated at 1,000 degrees.



Hamburg;	July 28, 1943:	~ 50,000- 80,000
Dresden;	February 13, 1945:	~ 35,000-100,000
Tokyo;	March 9-10,1945:	~100,000-200,000

Stack (chimney) effect in thermodynamics

$$v = 0.65 \cdot \sqrt{2g \cdot H \cdot \left(\frac{T_i - T_o}{T_i} \right)}$$

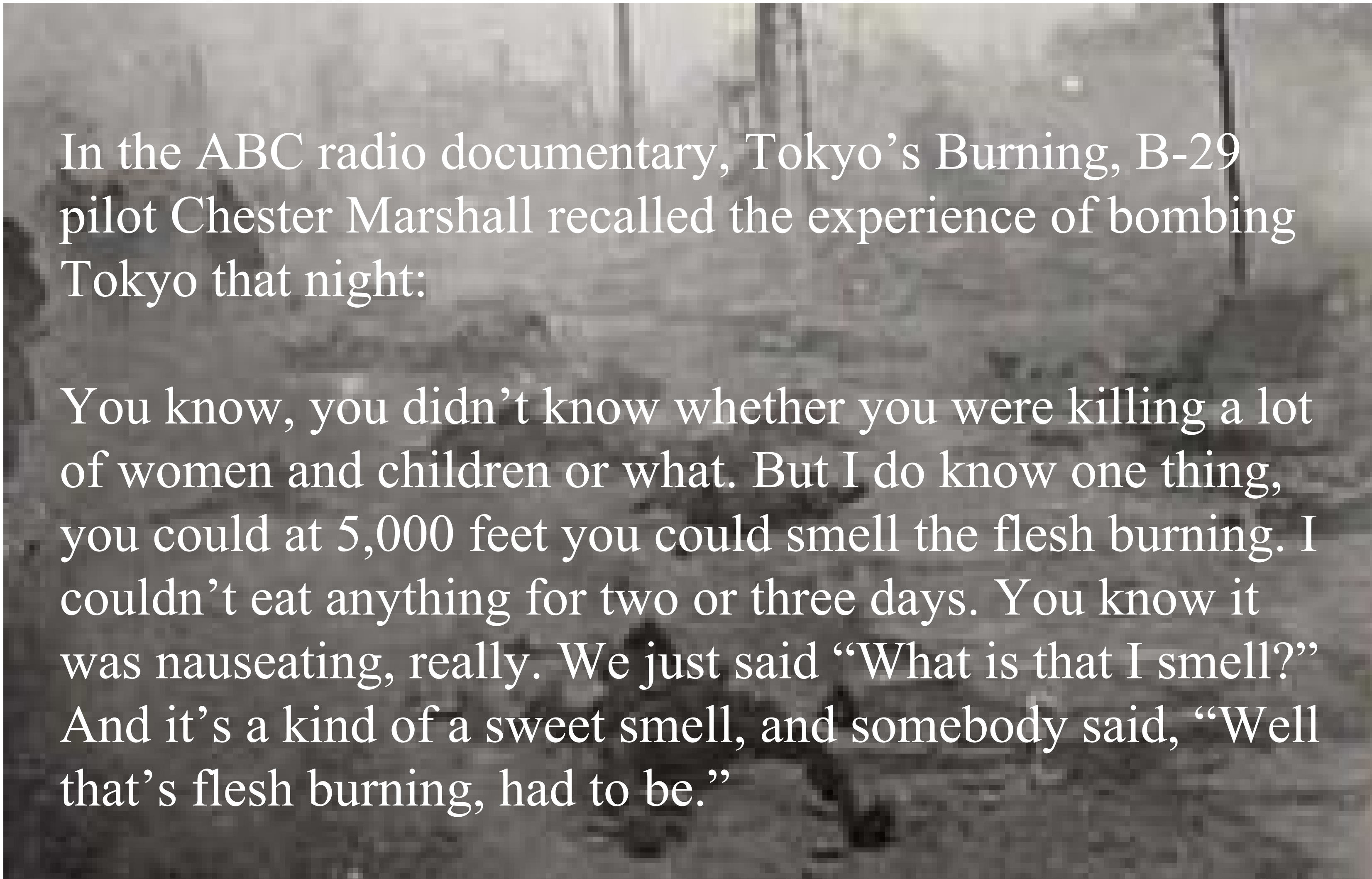
v=wind velocity in m/s
g=9.8 m/s^2 earth acceleration
H=height of heat column in [m]
T_o=outside temperature, K
T_i=inside temperature in K

For typical firestorm:
H ≈ 1000-2000 m
$T_i \approx 1300$ K
$T_o \approx 300$ K

⇨ v ≈ 98m/s = 220 miles/h

Hurricane speeds ~100 miles/h

Victims



In the ABC radio documentary, Tokyo's Burning, B-29 pilot Chester Marshall recalled the experience of bombing Tokyo that night:

You know, you didn't know whether you were killing a lot of women and children or what. But I do know one thing, you could at 5,000 feet you could smell the flesh burning. I couldn't eat anything for two or three days. You know it was nauseating, really. We just said "What is that I smell?" And it's a kind of a sweet smell, and somebody said, "Well that's flesh burning, had to be."

Technological Escalation in WW II

Technological escalation during World War II was more profound than in any other period in human history. More new inventions, certainly as measured by such means as patent applications for dual-use technology and weapon contracts issued to private contractors, were deployed to the task of killing humans more effectively, and to a much lesser degree, avoiding being killed. Unlike technological escalation during World War I, it was generally believed that speed and firepower, not defenses or entrenchments, would bring the war to a quicker end. Second goal was to weaken enemy moral by direct attacks of civil population designed for maximizing devastation.

The Beginning of the Nuclear Age

Albert Einstein
Old Grove Rd.
Nassau Point
Peconic, Long Island

August 2nd, 1939

F.D. Roosevelt,
President of the United States,
White House
Washington, D.C.

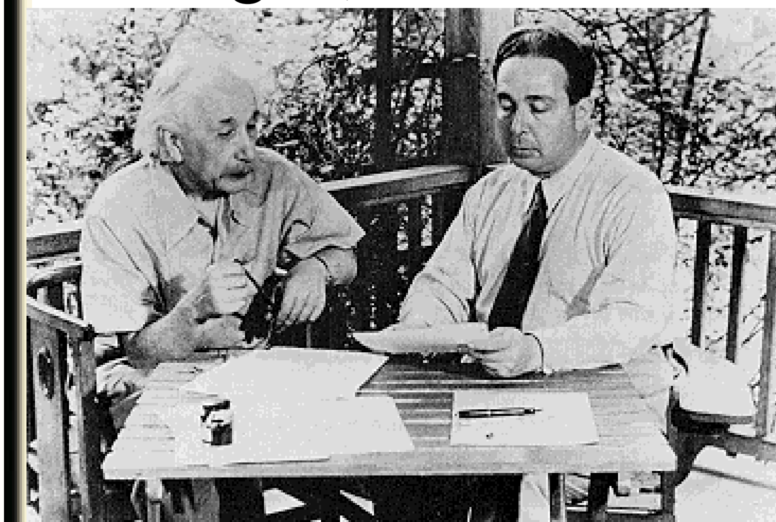
Sir:

Some recent work by E.Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations:

In the course of the last four months it has been made probable - through the work of Joliot in France as well as Fermi and Szilard in America - that it may become possible to set up a nuclear chain reaction in a large mass of uranium,by which vast amounts of power and large quant-

The Einstein Szilard letter to Roosevelt

Aug. 2, 1939



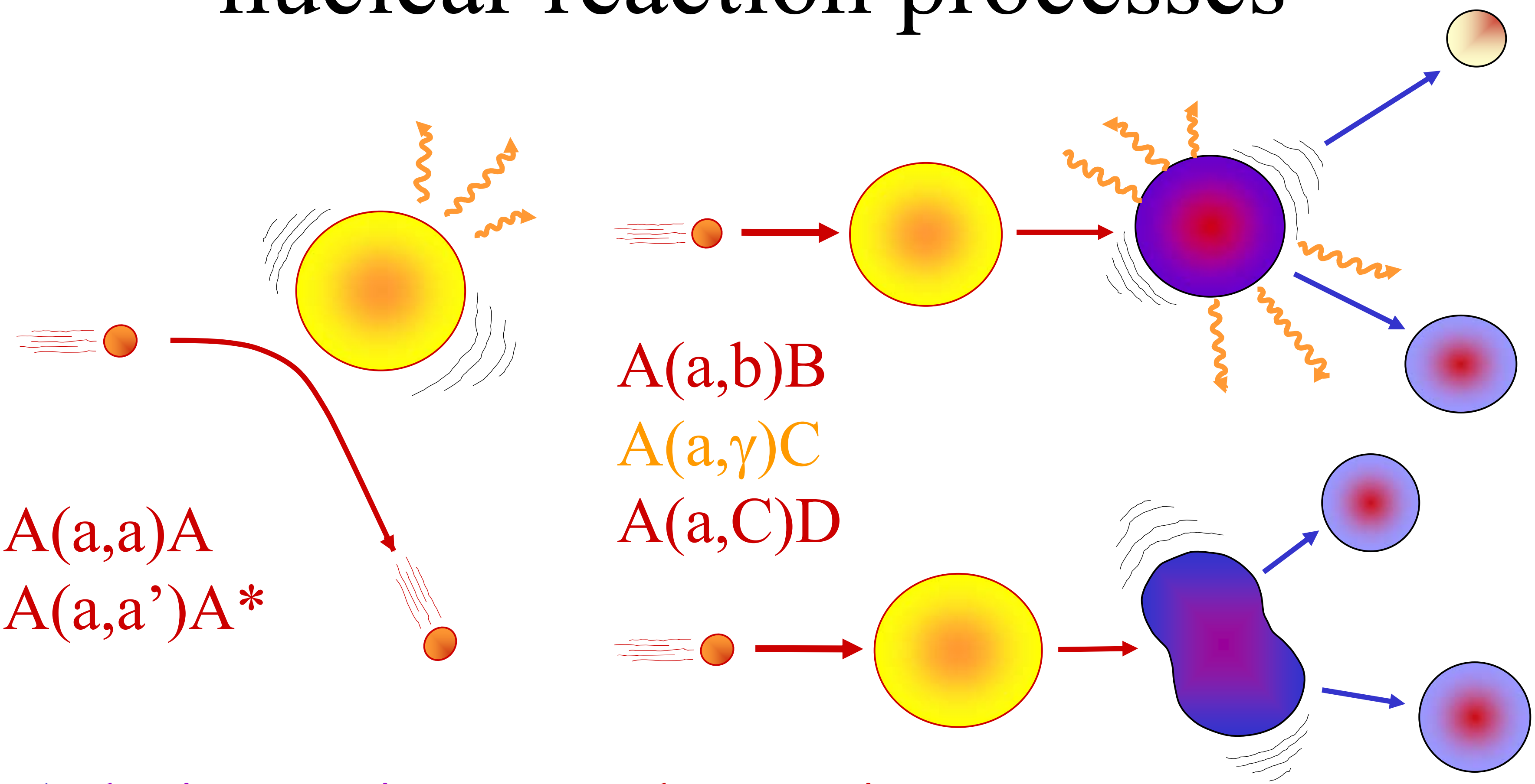
"Because of the danger that Hitler might be the first to have the bomb, I signed a letter to the President which had been drafted by Szilard. Had I known that the fear was not justified, I would not have participated in opening this Pandora's box, nor would Szilard. For my distrust of governments was not limited to Germany."

Rumors or Reality?

American and British nuclear physicists felt they needed to start a A-bomb project to avoid falling behind their German counterparts. They feared Hitler's forces would be the first to have use of atomic arms. This evaluation was based on a number of considerations:

- The pre-war stop of uranium export
- The high caliber of German theoretical and experimental physicists like Otto Hahn, Paul Harteck, Werner Heisenberg, Fritz Strassmann, and Carl-Friedrich von Weizsäcker;
- German control of Europe's only uranium mine after the conquest of Czechoslovakia;
- German capture of the world's largest supply of imported uranium with the fall of Belgium;
- German possession of Europe's only cyclotron with the fall of France;
- German control of the world's only commercial source of heavy water after its occupation of Norway.

nuclear reaction processes

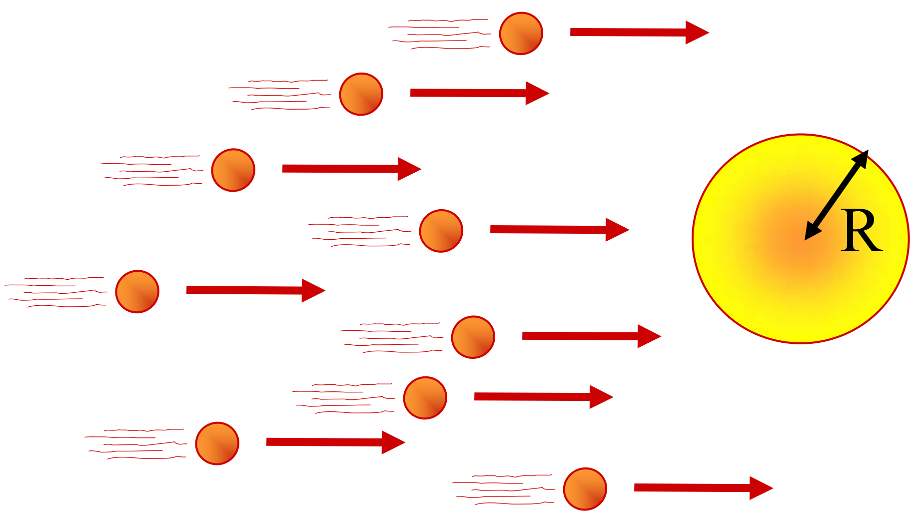


(in-) elastic scattering
⌗ particle energy
⌗ X-ray radiation
⌗ γ-ray radiation

nuclear reaction processes
⌗ γ-radiation
⌗ particle break-up
⌗ fission

Some background

The probability for a reaction to occur is the cross-section σ!



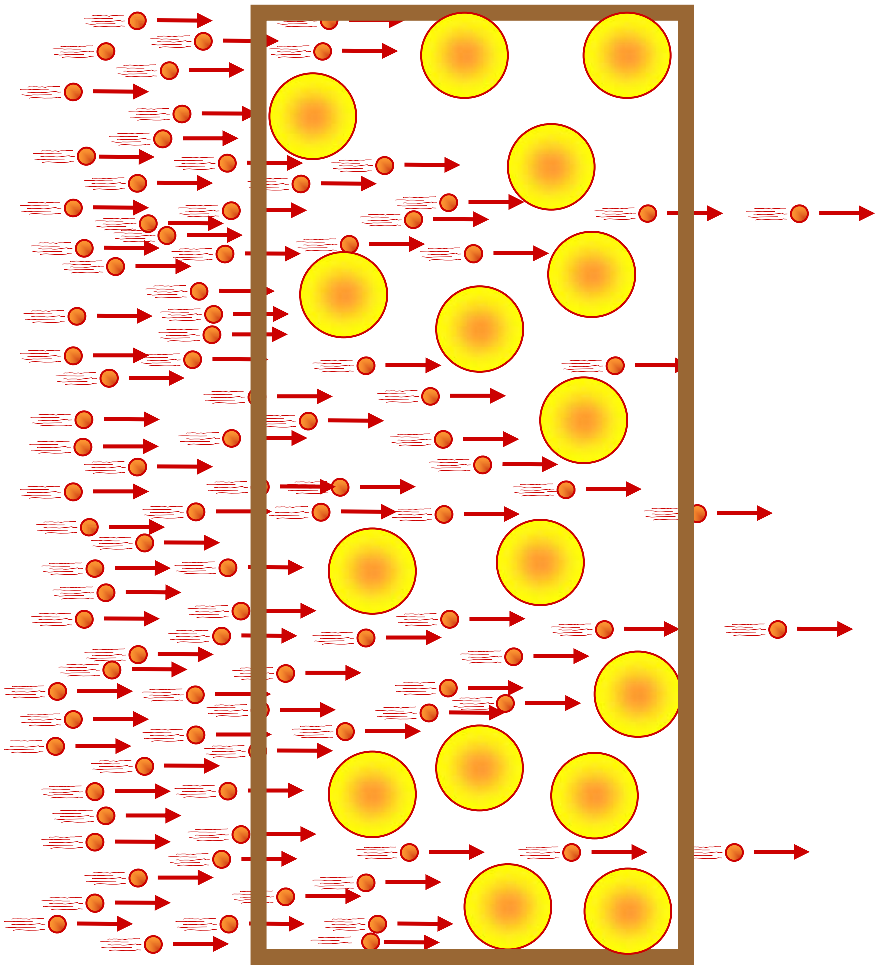
probability for incoming beam to hit a target nucleus with radius R: $\sigma \approx \pi R^2$

Typical radius of nucleus $\approx 10^{-12}$ m

cross section $\approx$ area, unit barn:

$1 \text{ barn} = 1 \cdot 10^{-24} \text{ cm}^2$

Total probability for reaction ≈ Yield



If target has thickness d,
and target material has
nuclei/volume: n_0 [part./cm^3]

$$Y = \sigma \cdot n_0 \cdot d$$

The yield gives the intensity of the characteristic signal from the reaction process per incoming particle with the cross section σ ! It also gives the number of reaction products per incoming particle!

Fission based explosions

Trigger ^{235}U fission through neutron bombardment each fission process generates 3 neutrons (- neutron losses)

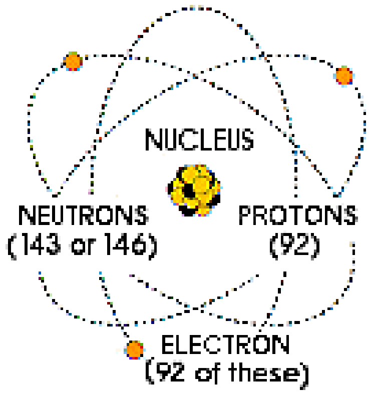
Required for the success of explosion is:

- High neutron capture probability σ_{fiss} (cross section) (measurements with neutron beams on fissionable material)
- Maintaining high neutron flux n_n (measurement of neutron production reactions)

$$Y_{fiss} = \sigma_{fiss}\left[barn\right]\cdot n_{^{235}U}\left[part\right]\cdot n_n\left[s^{-1}cm^{-2}\right]$$

$$E_{fission} = \varepsilon \cdot Y_{fiss}$$

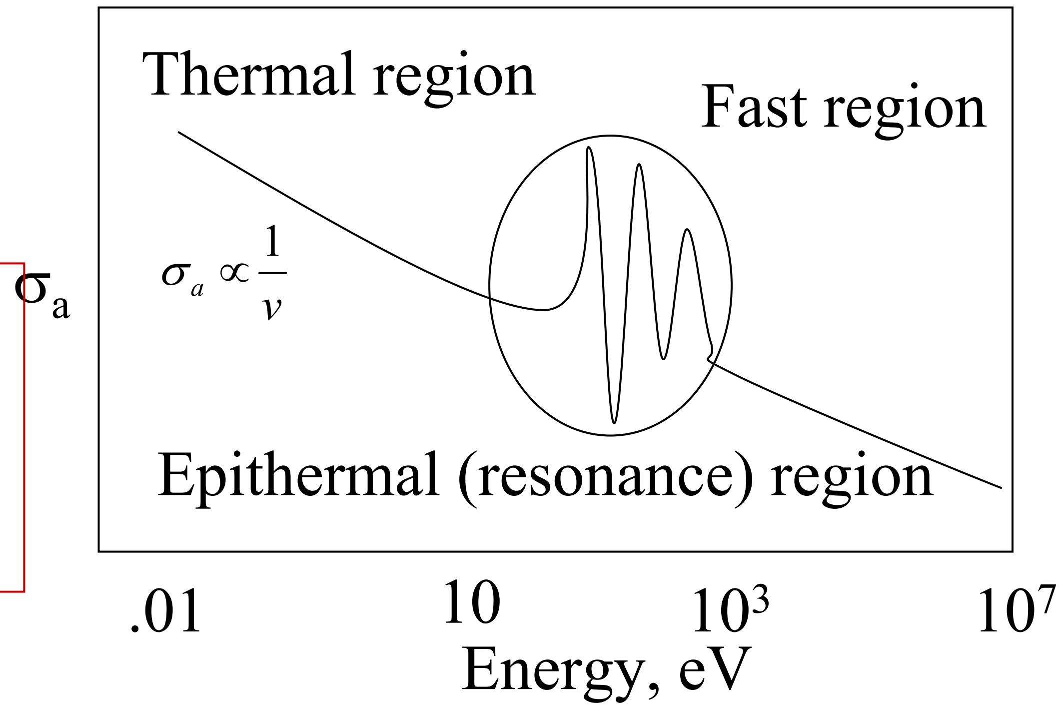
Efficiency factor



1/v law of neutron capture

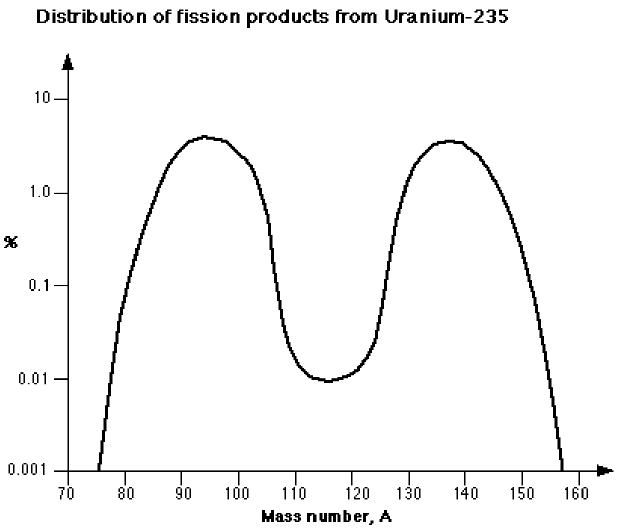
Neutrons have no charge! Neutron capture cross sections are inverse proportional with neutron velocity since no deflective Coulomb barrier is involved. As lower the velocity as higher the reaction probability !

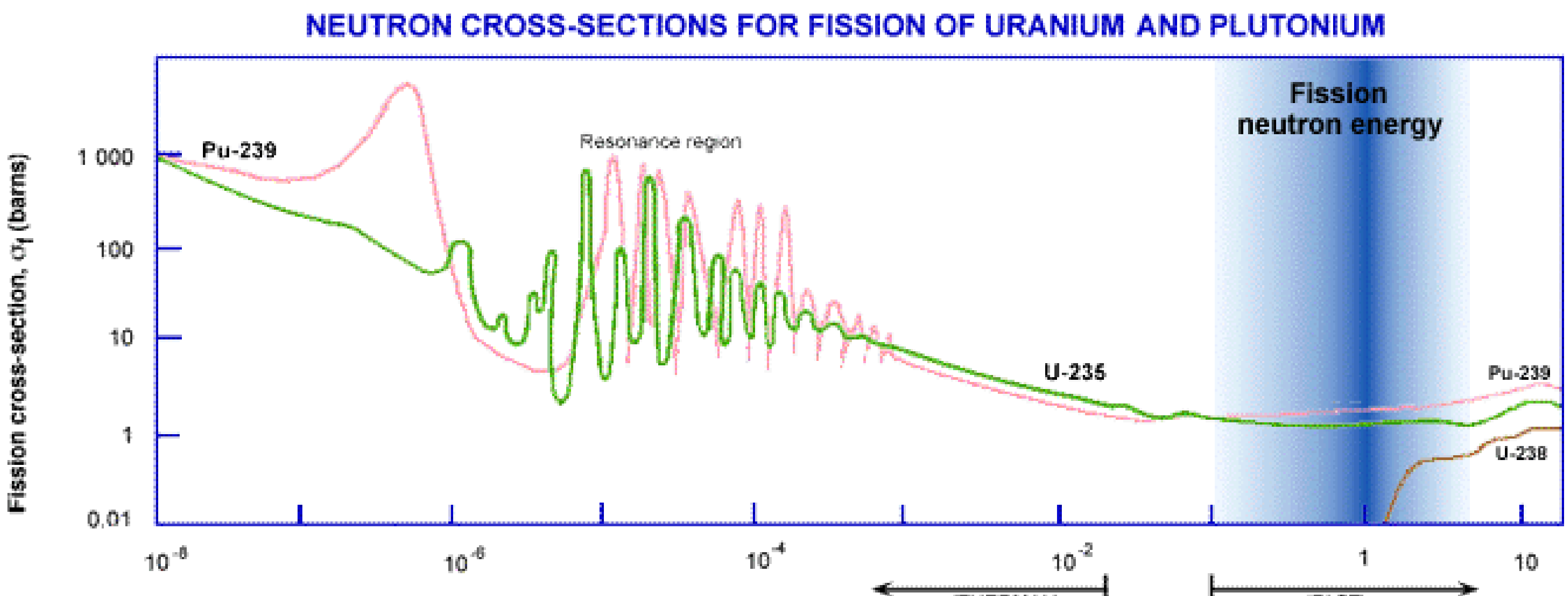
Introduces the need For “moderating” Neutrons to low “thermal” velocities



Fission cross section

Experimental results from fission studies





Sources: OECD / NEA 1989, Plutonium fuel - an assessment.
Taube 1974, Plutonium - a general survey.
1 barn = 10^{-28} m2, 1 MeV = 1.6×10^{-13} J

Moderators

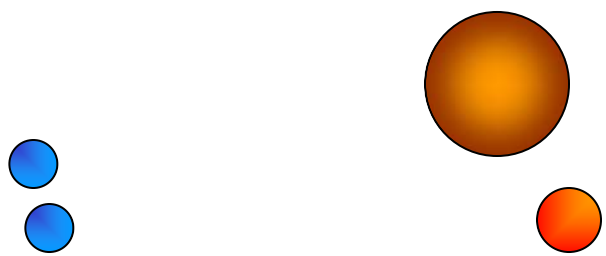
Example: neutron capture probability for 5 MeV neutrons from reaction is ~1 barn (1barn =10^{-24} cm^2). What is the capture cross section for thermal neutrons (E=0.026eV)

$$\sigma(E) \propto \frac{1}{v} \propto \frac{1}{\sqrt{E}}; \quad \sigma(E_{therm}) = \sqrt{\frac{E_{fast}}{E_{therm}}} \cdot \sigma(E_{fast})$$

$$\sigma(0.026) = \sqrt{\frac{5 \cdot 10^6}{0.026}} \cdot 1\, barn = 1.4 \cdot 10^4 \; barn$$

Four orders of magnitude improvement by slowing down the neutrons!!! What is the best slow down mechanism?

Scattering and Energy Loss



Best neutron moderators are light mass materials because of large energy transfer in scattering event: Graphite C, heavy water D_2O (low absorption cross section is crucial!)

Moderators

Graphite: easy to originate from carbon, obvious first choice

Easy to machine for industrial purposes!

Heavy Water is dideuterium oxide, or D_2O or ^2H_2O. Gilbert N. Lewis isolated the first sample of pure heavy water in 1933.

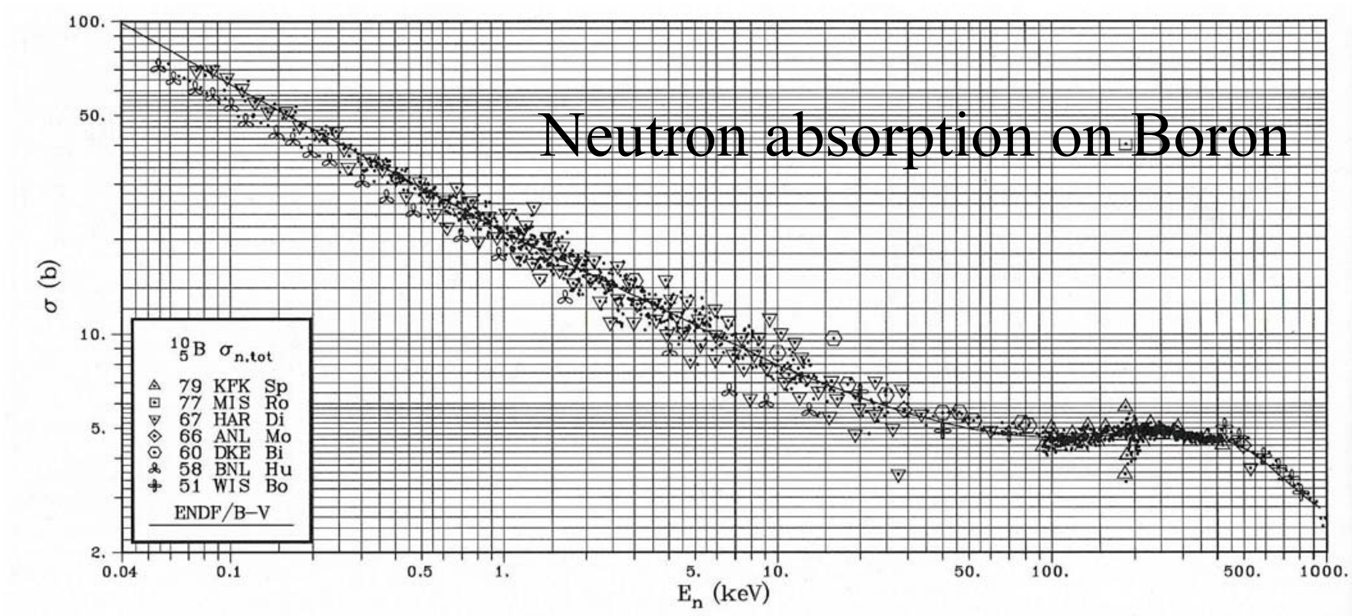
German Choices

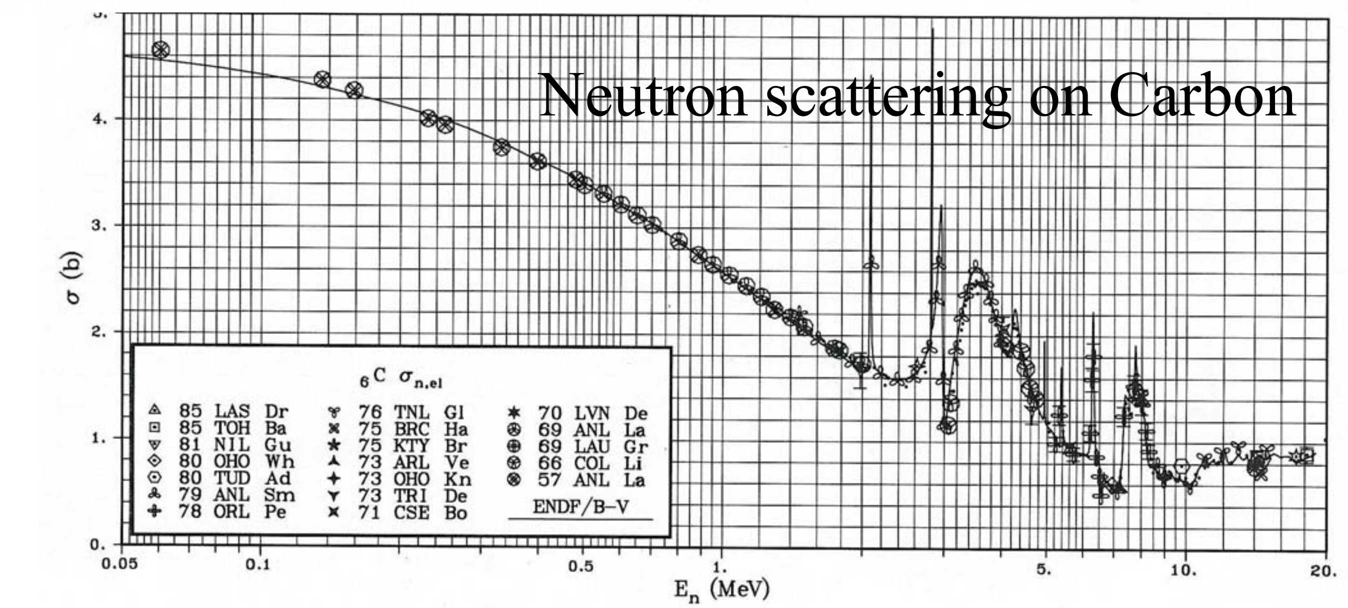
Walter Bothe, the leading experimental nuclear physicist in Germany, did the crucial experiment and concluded that carbon in the form of graphite would not work. In America, Enrico Fermi did a similar experiment and concluded that graphite was marginal. He suspected that an impurity in the graphite was responsible for the problem. Leo Szilard, who was working alongside Fermi, had studied chemical engineering before going into physics. He remembered that electrodes of boron carbide were commonly used in the manufacture of graphite. It was known that one atom of boron absorbs about as many slow neutrons as 100 000 atoms of carbon. Very small boron impurities would "poison" the graphite for use as a nuclear reaction moderator. Szilard therefore went around to the American graphite manufacturers and convinced one of them to make boron-free graphite. Using this pure graphite as the moderator, the American group achieved a chain reaction on 2 December 1942.

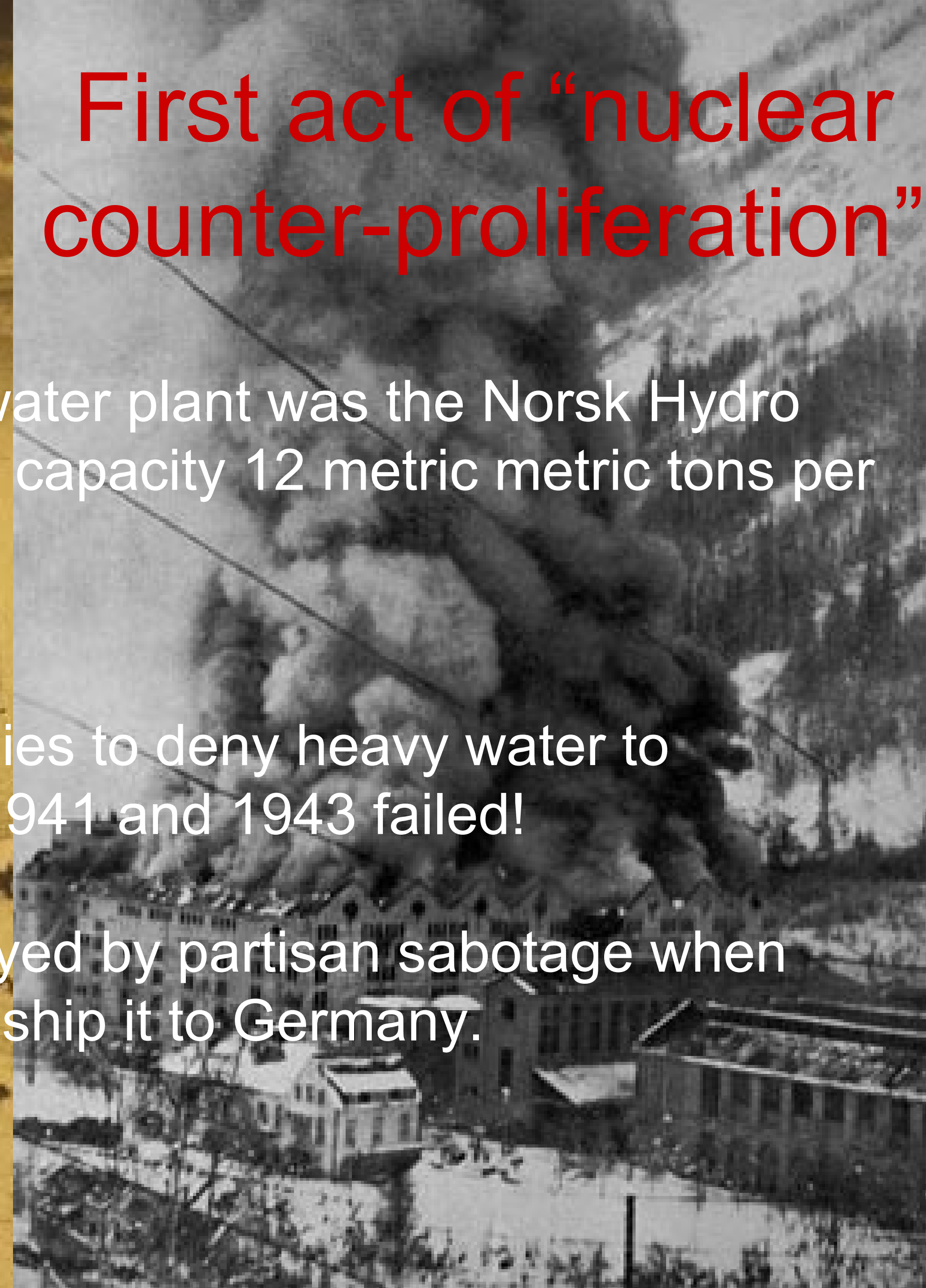
The German team, however, needed to use heavy water, D_2O. Ordinary water contains heavy water at a rate of about 1 part in 10 000. The two can be separated by repeated electrolysis, which requires large amounts of electric power in close proximity to a water source. The Germans had this at a hydroelectric plant in occupied Norway, and they set up a separation facility there.

Hans Bethe in Physics Today Vol 53 (2001)

Comparison of cross sections







First act of “nuclear counter-proliferation”

The first commercial heavy water plant was the Norsk Hydro facility in Norway (built 1934, capacity 12 metric metric tons per year).

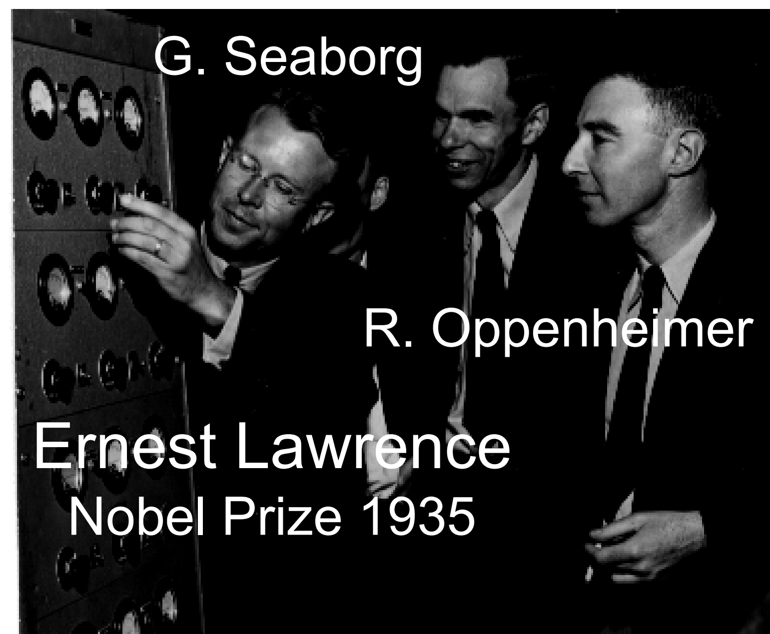
Plant was attacked by the Allies to deny heavy water to Germany. Attacks between 1941 and 1943 failed!

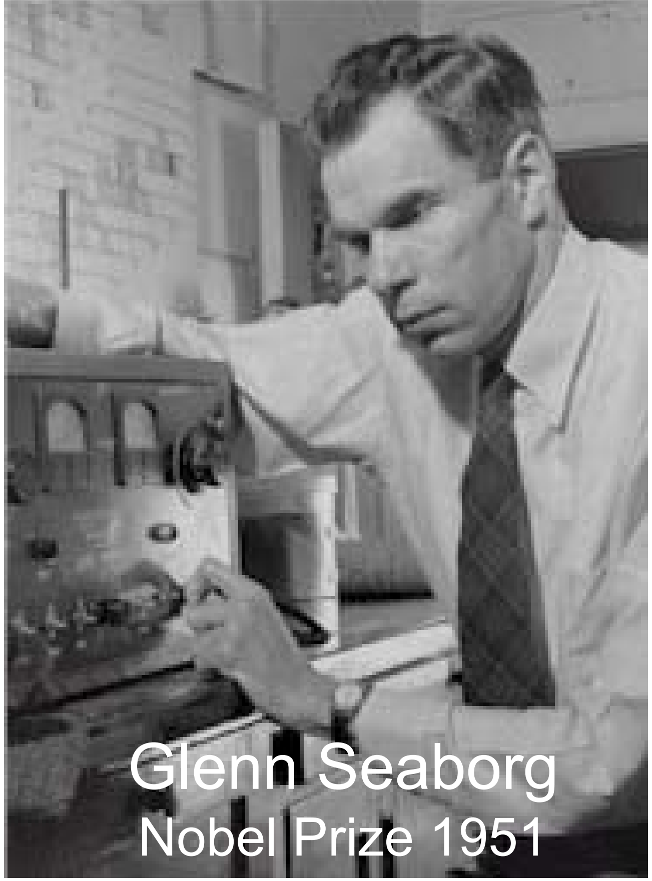
However, D_2O supply destroyed by partisan sabotage when German government tried to ship it to Germany.

Uranium ^{235}U separation

Natural uranium contains only 0.7% of the ^{235}U isotope. The remaining 99.3% is mostly the ^{238}U isotope. To achieve fission of large amounts of ^{235}U separation techniques are required.
Reactors operate at 3-4% enrichment, weapons require 90% enrichment.
Three methods have been developed :

1. Separation by diffusion through porous membrane; diffusion rate ~ $1/M^2$ (circular separation)
2. Electromagnetic separation in "cyclotrons"
3. Centrifugal separation (developed In 1940, but only applied in 60ties).





Plutonium

Seaborg discovered plutonium at U.C Berkeley, Feb. 23, 1941.

^{239}Pu also undergoes fission and can be made from ^{238}U.

The “breeding process” requires the exposure of ^{238}U to high neutron flux!

- ${}^{238}_{92}U + {}^{1}_{0}n \rightarrow {}^{239}_{92}U$ neutron capture reaction
- ${}^{239}_{92}U \rightarrow {}^{239}_{93}Np + \beta^-$ $t_{1/2}$= 23.5 min
- ${}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + \beta^-$ $t_{1/2}$= 2.35 days

He was discoverer of plutonium and all further transuranium elements through element 102!

The Manhattan Project

The Military Director of the Manhattan Project General Leslie Groves.

In response to the perceived German threat the United States initiated its own program for the development of an “Atomic Bomb” under the Army Corps of Engineers in June 1942.

Groves projected three sites for the development of nuclear weapon production with the goal of:

1. Enrichment of ^{235}U
2. Generating ^{239}Pu
3. bomb assembling and testing

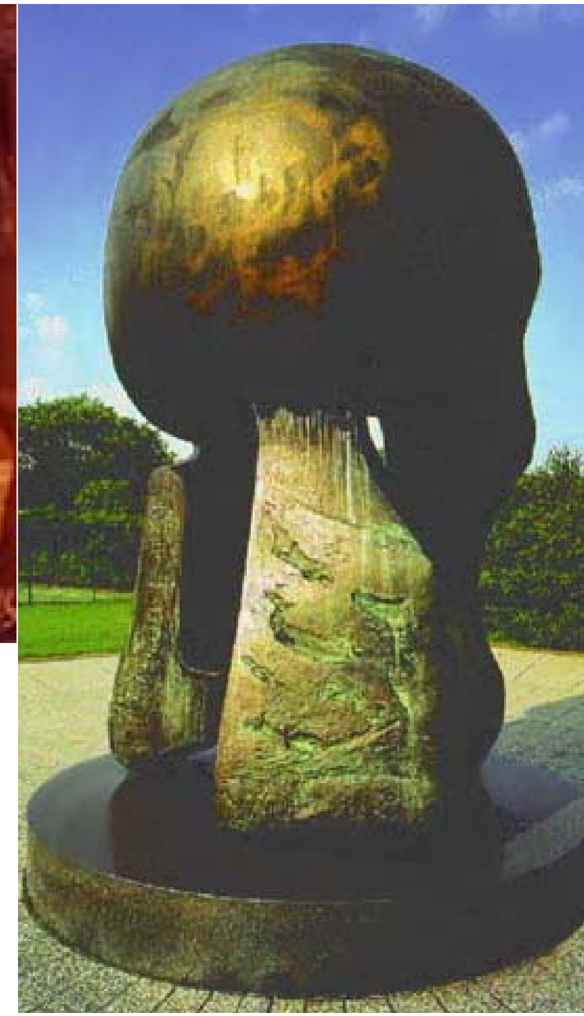
Basic goal was to probe and utilize all of the available technical possibilities!

J. Robert Oppenheimer

After graduating from Harvard in 1925 and studying (unsuccessfully) at Cambridge under Ernest Rutherford, he obtained his PhD in Göttingen, Germany. In 1929 he returned to the United States to positions at Berkeley and Cal Tech. He was appointed by General Groves in 1942 as the Scientific Director of the Manhattan Project.

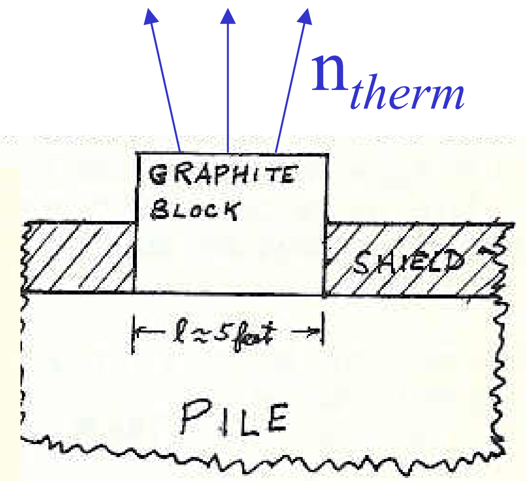
Groves said of Oppenheimer, "He's a genius. A real genius...Why, Oppenheimer knows about everything. He can talk to you about anything you bring up. Well not exactly. I guess there are a few things he doesn't know about. He doesn't know anything about sports."

The first operating Reactor



The basic research for understanding fission properties was performed at the University of Chicago. For this purpose Enrico Fermi built the first nuclear reactor, CP-1, in a squash court under the football stadium. The first sustained nuclear reaction occurred on Dec. 2, 1942!

The Pile



Practical use of this data is made in the design of thermal columns. A column of graphite with base of dimensions $\ell \times \ell$ is placed against a nuclear pile which is a source of fast neutrons. At distances greater than a few feet from the pile, the neutrons in the graphite will be thermal.

Assuming $q_T = 0$ except in this small layer near the pile and using IX.19, the equation for $n(\underline{r})$ is

$$\nabla^2 n - \frac{n}{a^2} = 0$$

The approximate boundary conditions are

$$n = 0 \text{ at} \begin{cases} x = 0 \text{ and } \ell \\ y = 0 \text{ and } \ell \end{cases}$$

Let $$n(\underline{r}) = \sum_{j,k=1}^{\infty} n_{jk}(z) \sin\frac{\pi j x}{\ell} \sin\frac{\pi k y}{\ell}$$

$$\frac{d^2 n_{jk}}{dz^2} - \left[\frac{\pi^2}{\ell^2}(j^2+k^2) + \frac{1}{a^2}\right] n_{jk} = 0$$

$$n_{jk}(z) = C e^{-\frac{1}{b_{jk}} z} \quad \text{where} \quad \frac{1}{b_{jk}} \equiv \sqrt{\frac{1}{a^2} + \frac{\pi^2}{\ell^2}(j^2+k^2)}$$

b_{jk} is maximum for the (1,1) mode.

$$\frac{1}{b_{11}} = \sqrt{\frac{1}{a^2} + \frac{2\pi^2}{\ell^2}}$$

SUBSTANCE	ρ	a	λ	$\Lambda = \frac{3a^2}{\lambda}$
H_2O	1.0	2.85	.43	57
D_2O	1.1	170	2.4	36,500
Be	1.8	31	2.0	1,400
C	1.62	50	2.5	3,000

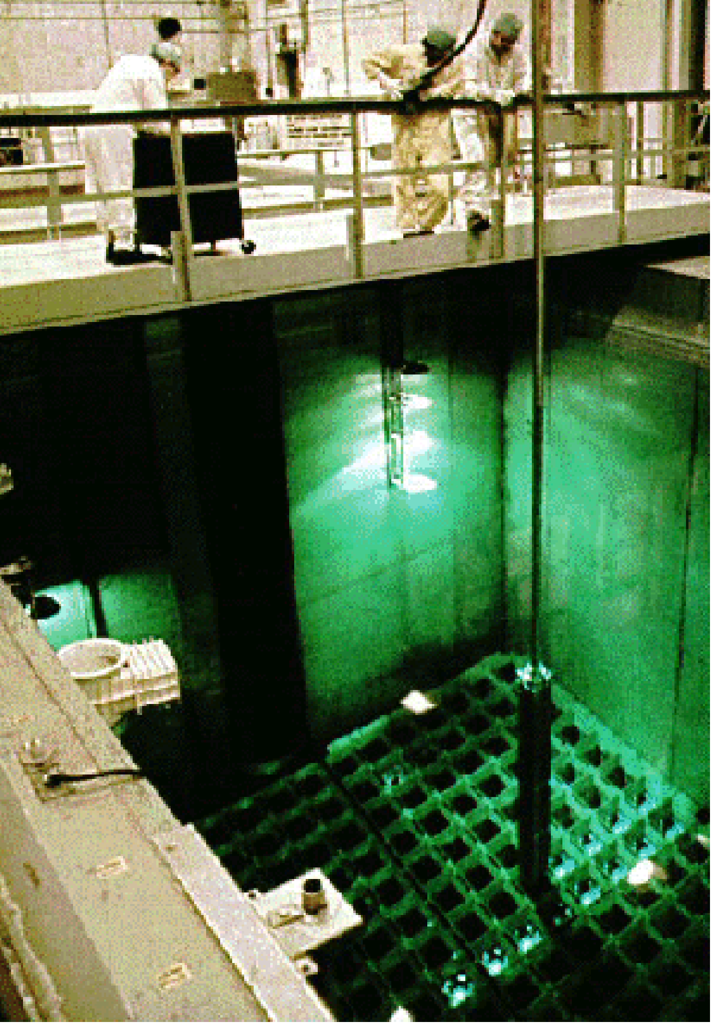
EXPERIMENTAL RESULTS

ρ: density
a: diffusion length
λ: distance between collisions
Λ: absorption mean free path
b: effective diffusion length for thermalization

For $\ell \gg a$; $b_{11} \approx a$

and for $\ell \ll a$; $b_{11} \approx \frac{\ell}{\sqrt{2}\pi}$ is the effective diffusion length

Thus b_{11} can reach its maximum value (a) by increasing ℓ.
The object is to get thermal neutrons out past the region of the nascent and higher energy neutrons which already reach out on the order of 50 cm ($\sqrt{\overline{R^2}} \approx 50$ cm). Thus $\ell > a$ is a condition for building a thermal column.



CP-1 Nuclear Reactor

The CP-1 used 235 enriched uranium metal from Iowa State.

As moderator for slowing down the neutrons to thermal velocities the reactor used high purity graphite.

As control rods, for absorbing neutrons and preventing the reactor to become critical CP-1 used Cadmium rods. (Other neutron absorbing materials are e.g. Boron).

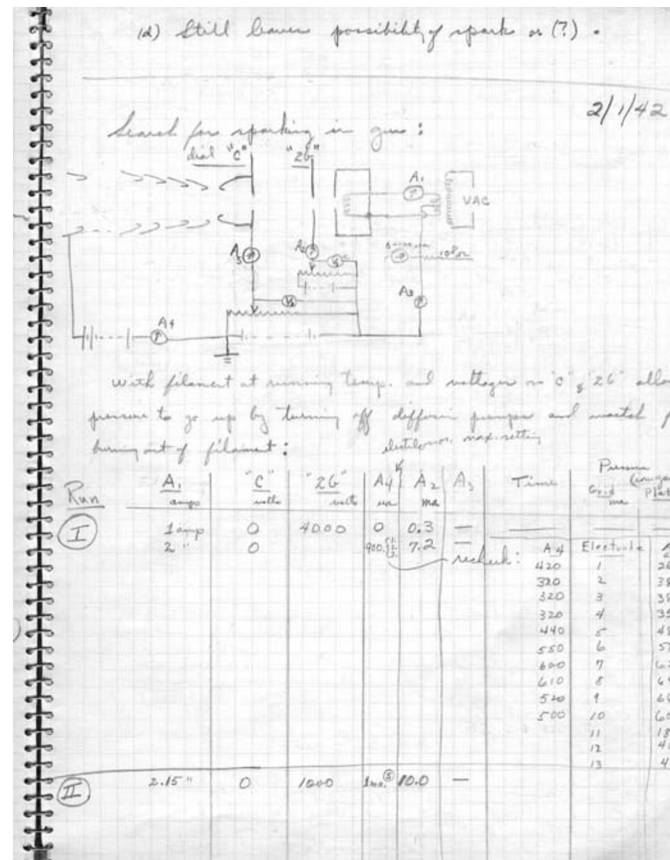
Moderators need high neutron scattering cross section,

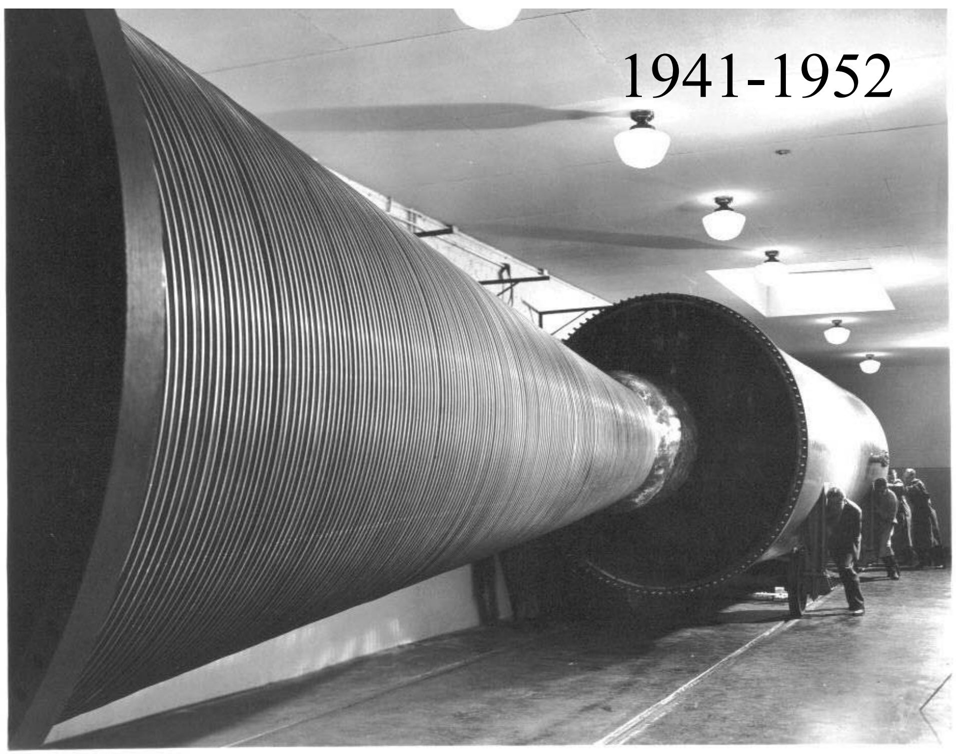
Absorbers require high neutron capture cross section.

Accelerator based radiation and material test facilities

Wisconsin: neutron production to test material fissibility

Notre Dame: high energy electron beam to test radiation





Oak Ridge

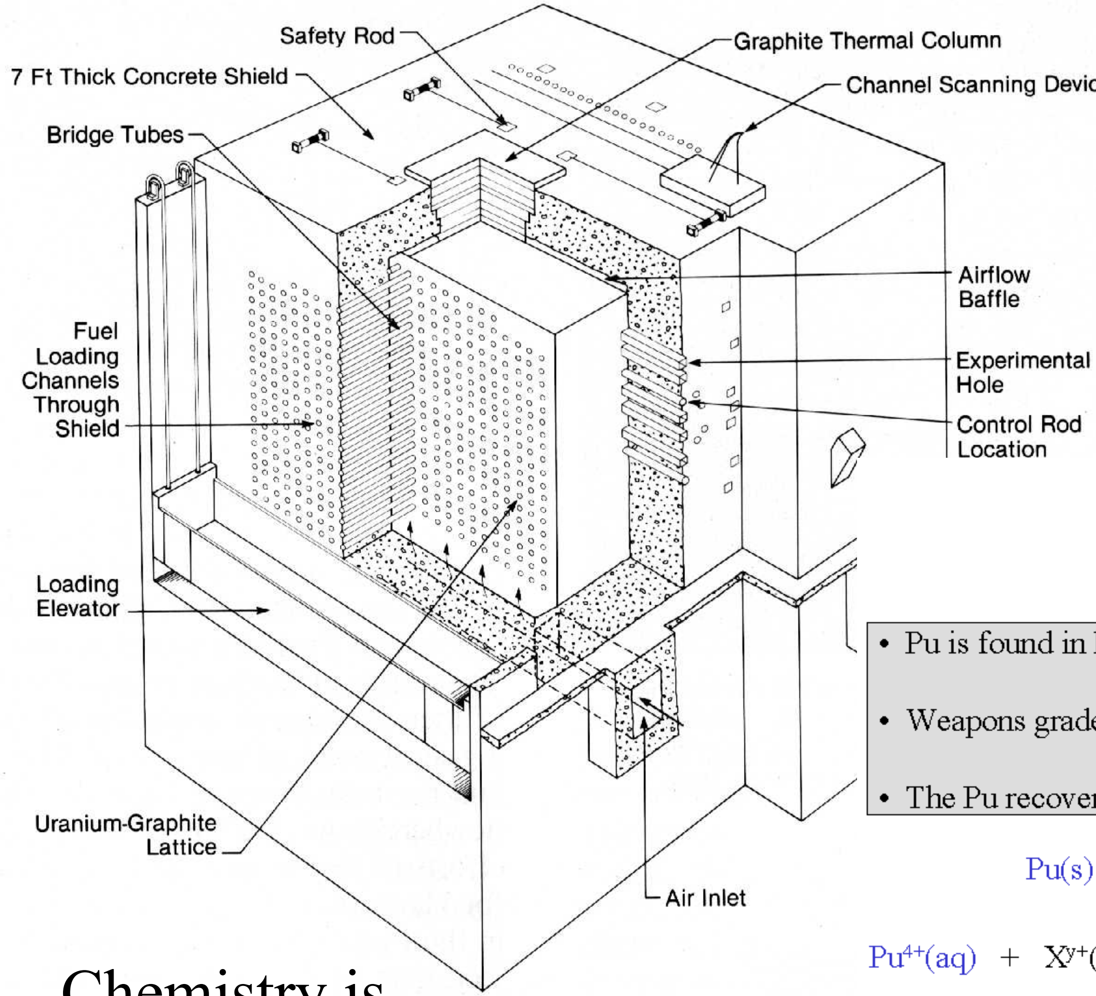
In a remote area near Knoxville, Tennessee a secret city was built. The main reason for choice of site was the abundant availability of Tennessee water power.

Primary purpose of the Oak Ridge facility was to enrich ^{235}U.

They also built a graphite reactor at site X-10 to study the production of plutonium. (Today site of ORNL)

Construction started in 1942

X-10 plutonium breeder reactor



Chemistry is necessary for generating weapon grade plutonium!

Bismuth Phosphate Process for Recovery of Plutonium

- Pu is found in low concentrations (<250 ppm) in reactor products.
- Weapons grade Pu must be chemically pure (< 1 part in 10^7 parts Pu).
- The Pu recovery for this process was 95% with < 1 part impurity in 10^7.

$$Pu(s) + X(s) \xrightarrow[H_2SO_4]{HNO_3} Pu^{4+}(aq) + X^{y+}(aq)$$

$$Pu^{4+}(aq) + X^{y+}(aq) + Bi^{3+}(aq) \xrightarrow{H_3PO_4} Pu_3(PO)_4(s) + X^{y+}(aq) + BiPO_4(s)$$

$$Pu_3(PO)_4(s) + BiPO_4(s) \xrightarrow[\text{oxid. agent}]{HNO_3} Pu^{6+}(aq) + Bi^{3+}(aq)$$

$$Pu^{6+}(aq) + Bi^{3+}(aq) \xrightarrow{H_3PO_4} Pu^{6+}(aq) + BiPO_4(s)$$

$$Pu^{6+}(aq) \xrightarrow{H_2O_2} PuO_2^{2+}(aq) \xrightarrow[\text{agent}]{\text{reducing}} Pu(s)$$

X(s) = fission products or uranium; $^{y+}$ = oxidation state

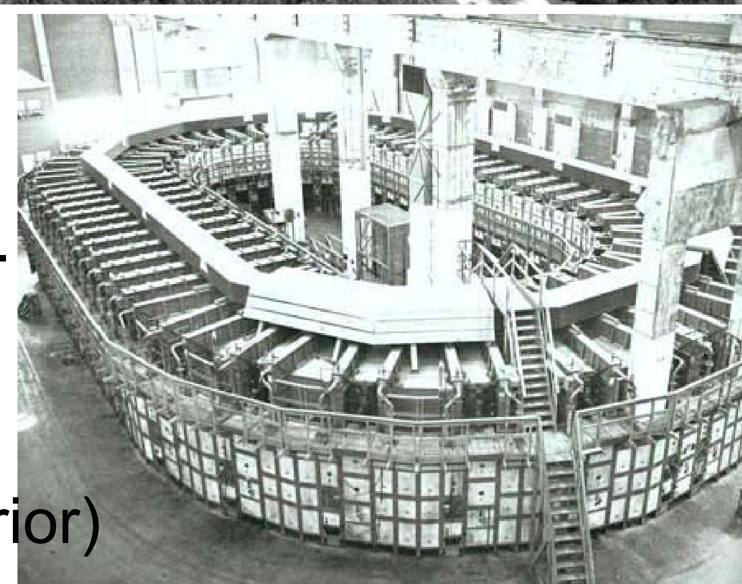
Y-12

Purpose of Y-12 plant:

Magnetic separation of ^{235}U from ^{238}U.

The work was overseen by Lawrence.

Operated 1943-1946
(diffusion based separation was superior)



Magnetic Separation

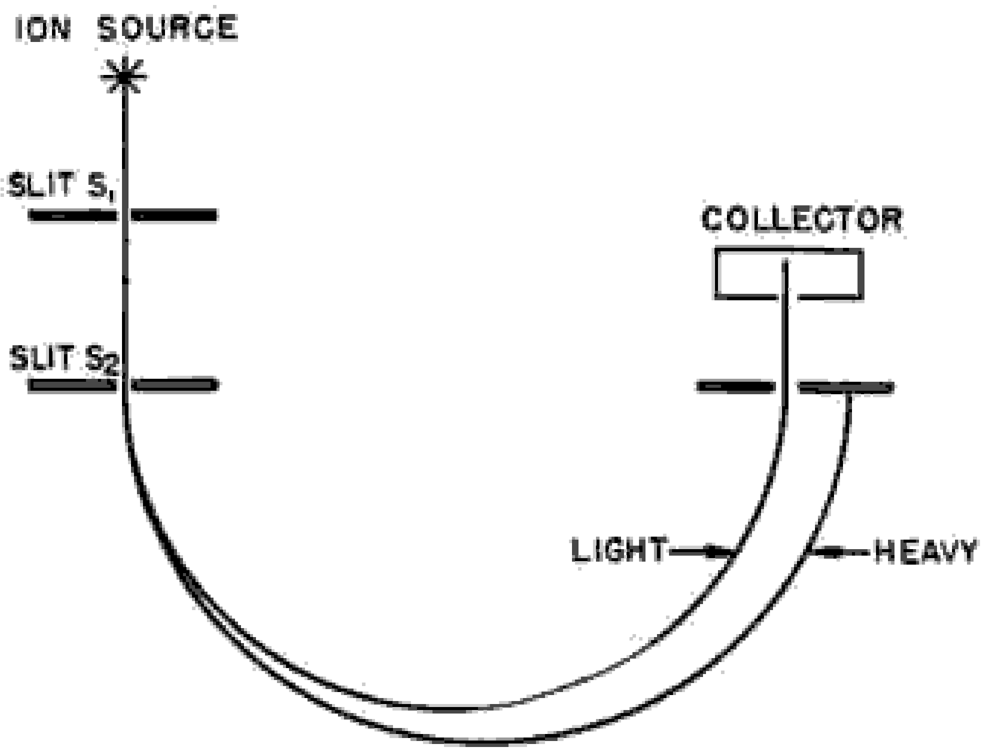
$$m\frac{v^2}{r} = e \cdot v \cdot B; \quad E = \frac{1}{2} m \cdot v^2$$

$$\frac{m \cdot v}{r} = e \cdot B; \quad \sqrt{2 \cdot E \cdot m} = e \cdot r \cdot B$$

$$m = \left(\frac{e \cdot r \cdot B}{2 \cdot E}\right)^2; \quad \frac{m_1}{m_2} = \left(\frac{r_1}{r_2}\right)^2$$

$$m_1 = 238, m_2 = 235, r_1 = 10m$$

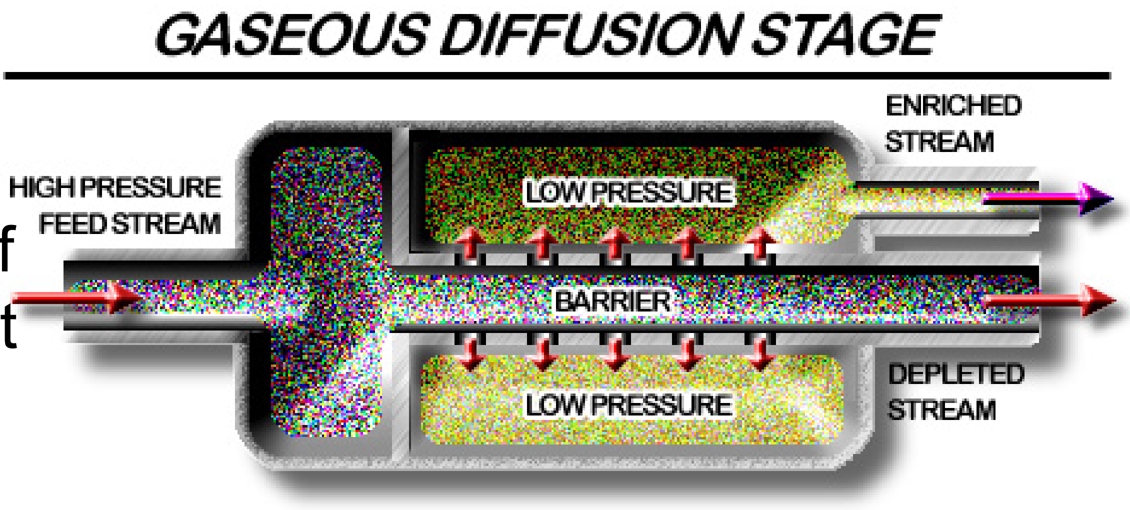
$$r_2 = r_1 \cdot \sqrt{\frac{m_2}{m_1}} = 10 \cdot \sqrt{\frac{235}{238}} = 9.94m$$



Constructed in 1943
Shut down in 1986!
2004 being dismantled!

Gaseous diffusion plant at Oak Ridge for enrichment of ^{235}U versus ^{238}U.

Based on Graham's Law of Effusion and the oddity that UF_6 is a gas when heated up to 135F.



Graham's Law of Effusion

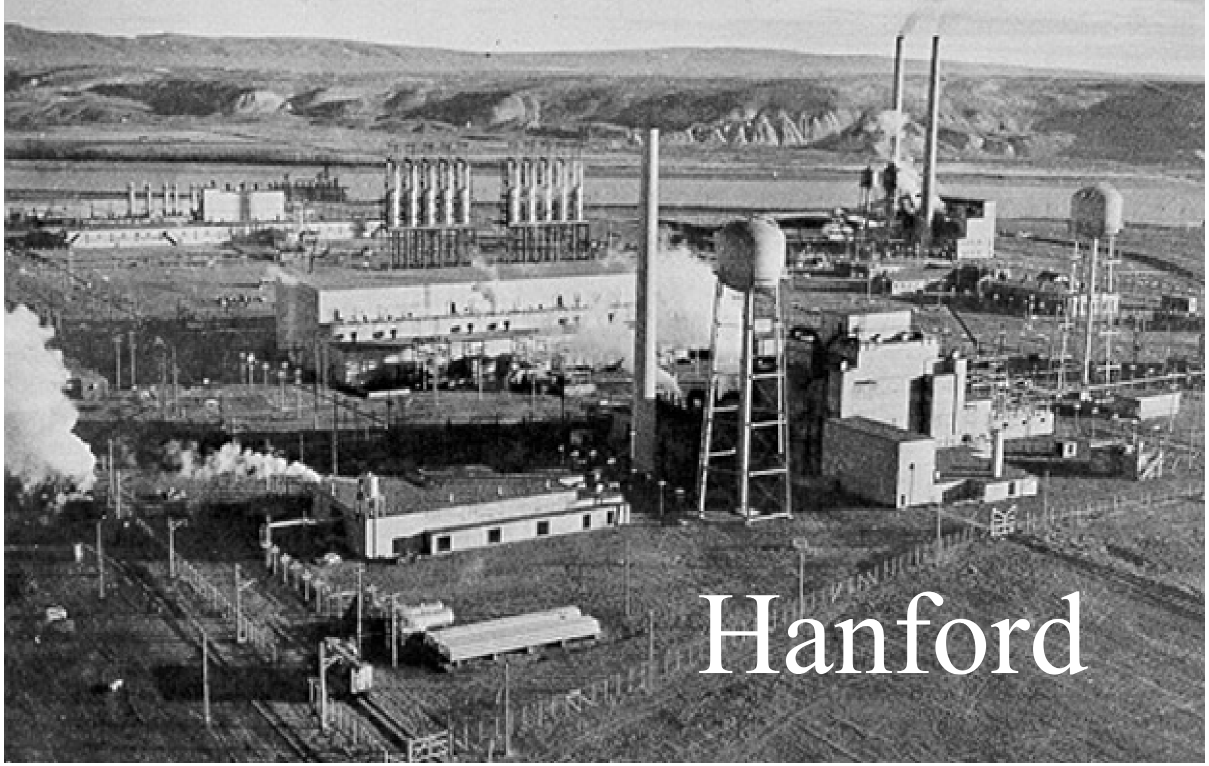
Assume two gases of molecular masses m_1 and m_2 diffuse. The ratio of time it takes for equal amounts of gas to reach a given distance is:

$$\frac{t_1}{t_2} = \sqrt{\frac{m_1}{m_2}}$$

This results from the dependence of the velocity of a gas particle in a Maxwell Boltzmann distribution.

$$\frac{t_1}{t_2} = \sqrt{\frac{m_1}{m_2}} = \sqrt{\frac{235}{238}} = 0.99$$

Several subsequent diffusion separator stations necessary for gradual slow enrichment.

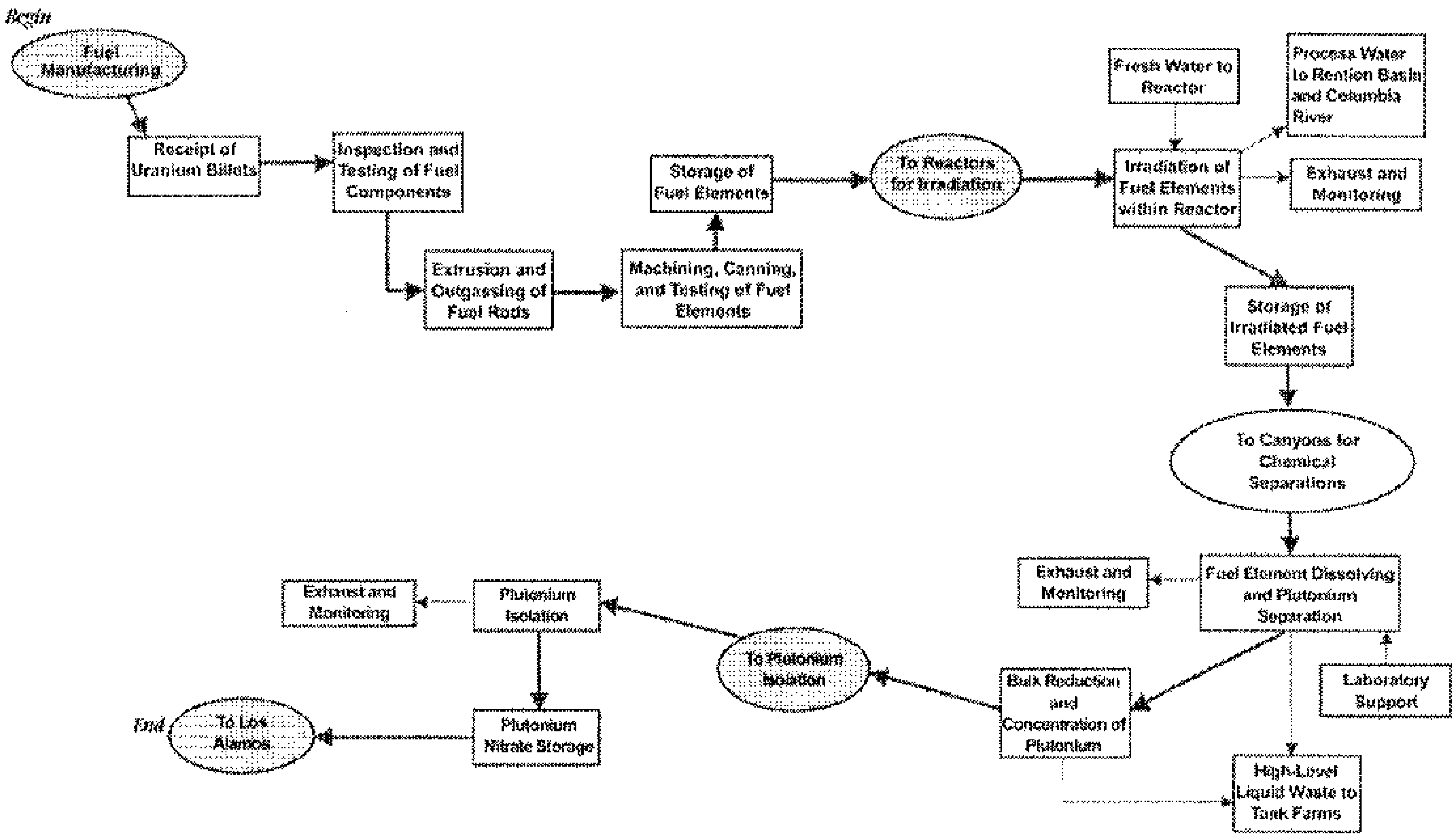


Constructed in 1943 as follow up on X-10 in Oak Ridge as main site for industrial plutonium production shut-down in 1963! Represents a major nuclear waste problem

Secret City on the Columbia River in Washington State.

- A series of 9 nuclear reactors were designed to produce plutonium.
- A chemical plant to process material and purify plutonium
- Storage site for the resulting nuclear waste

Plutonium-Production Cycle



Plutonium Production Cycle as It Existed throughout the Manhattan Project at the Hanford Site

Nuclear Waste

Solid waste:
burial grounds

Liquid waste:
retention basins,
reverse wells,
underground tanks
Columbia river

Gaseous waste:
($^{14}N(n,p)^{14}C$
toxic fumes)
ventilation and
exhaust into the
atmosphere

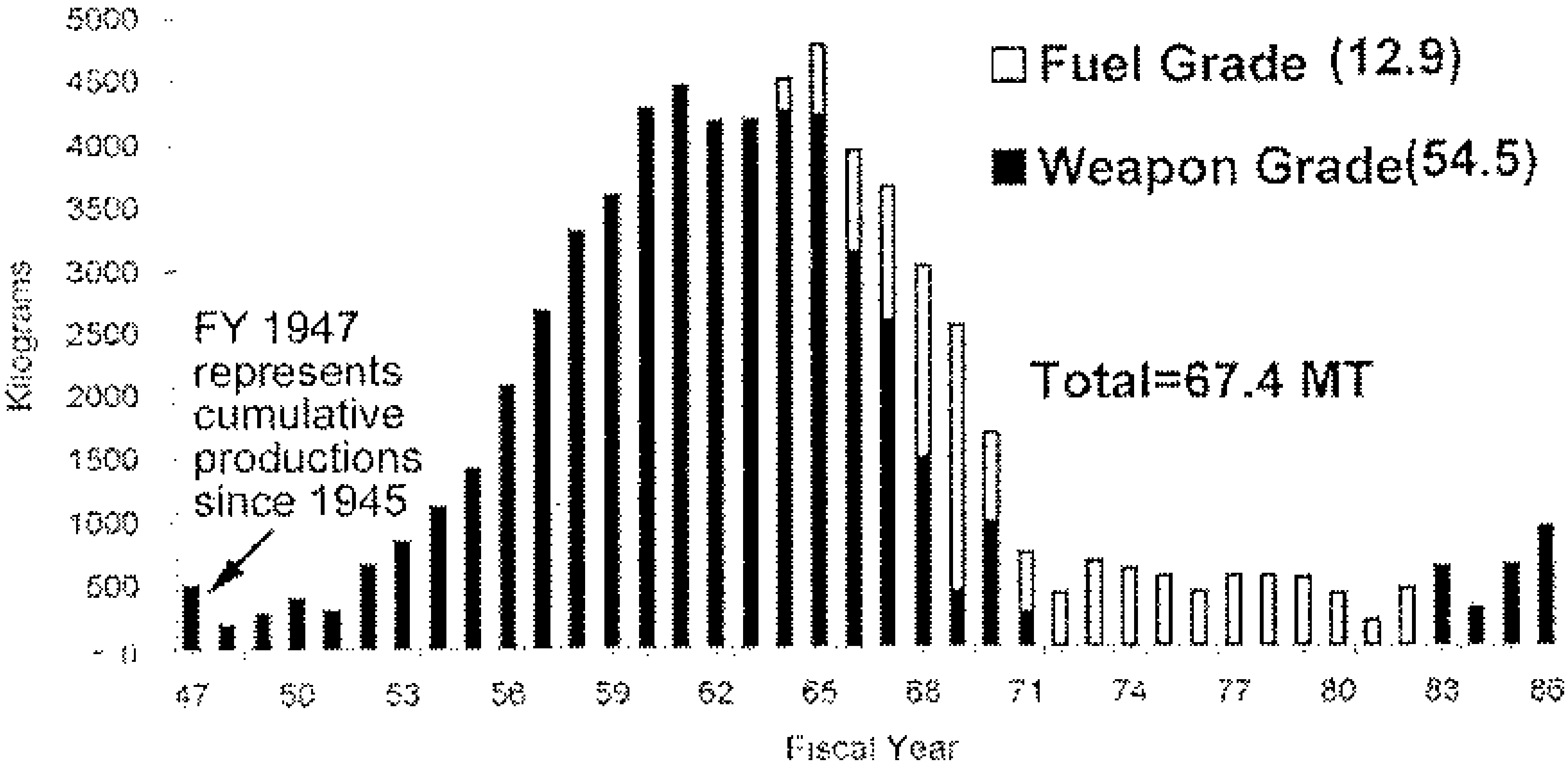
The 618-10 Burial Ground… *"consisted of trenches and rows of burial caissons known as "pipe fields." The caissons were made of 5 to 6 open-bottomed 55-gallon drums welded together and buried upright. From the mid-1950s until about 1960, solid radioactive wastes were collected from operations buildings in cardboard containers and then stored in lead pans known as "gunk catchers" and transported to 300 North [618-10] in shielded "load luggers." The cardboard waste containers then were dropped from the gunk catchers down the caissons, and the holes were filled with sand and dirt until radiation levels declined to a safe or "tolerance" reading. If radiation levels could not be reduced to tolerance ranges, concrete was poured down the hole until such levels were achieved."* - Gerber 1993a, p. 59

Left-over

Hanford is arguably the most contaminated site in North America. Cleanup costs are projected in the tens of billions of dollars, and requiring a fifty-year effort.

The Hanford Nuclear Site in southeastern Washington state stores 54 million gallons of dangerous high-level radioactive waste containing hundreds of millions of curies from the nation's nuclear weapons production process

Plutonium production at Hanford



Total Annual Production of Plutonium at the Hanford Site

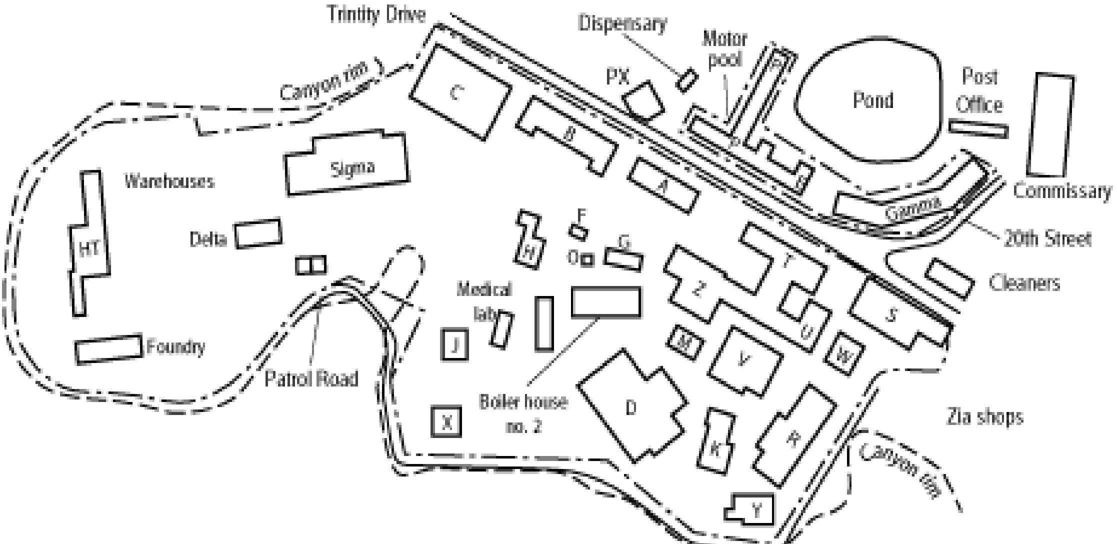
Los Alamos

Construction Secret City in the Sangre de Christo Mountains in New Mexico. The Los Alamos location was picked by Groves and Oppenheimer. On the site of a small boy's school.

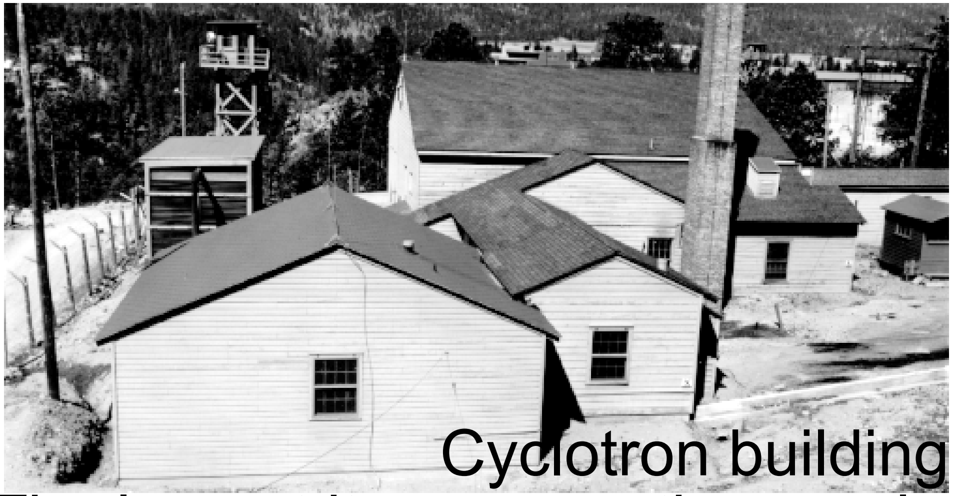
The sole purpose was to design and build the bombs.
Remote area, (Groves, Oppenheimer)
Easily to close off (Groves)
Stimulating environment (Oppenheimer)

Purchased for ~$ 400,000

Construction started in 1943 on top of Mesa



In January 1943, the population of Los Alamos had risen to 1,500.
By January 1944, it reached 3,500, and a year later it reached 5,700.


Cyclotron building

Accelerator test facilities

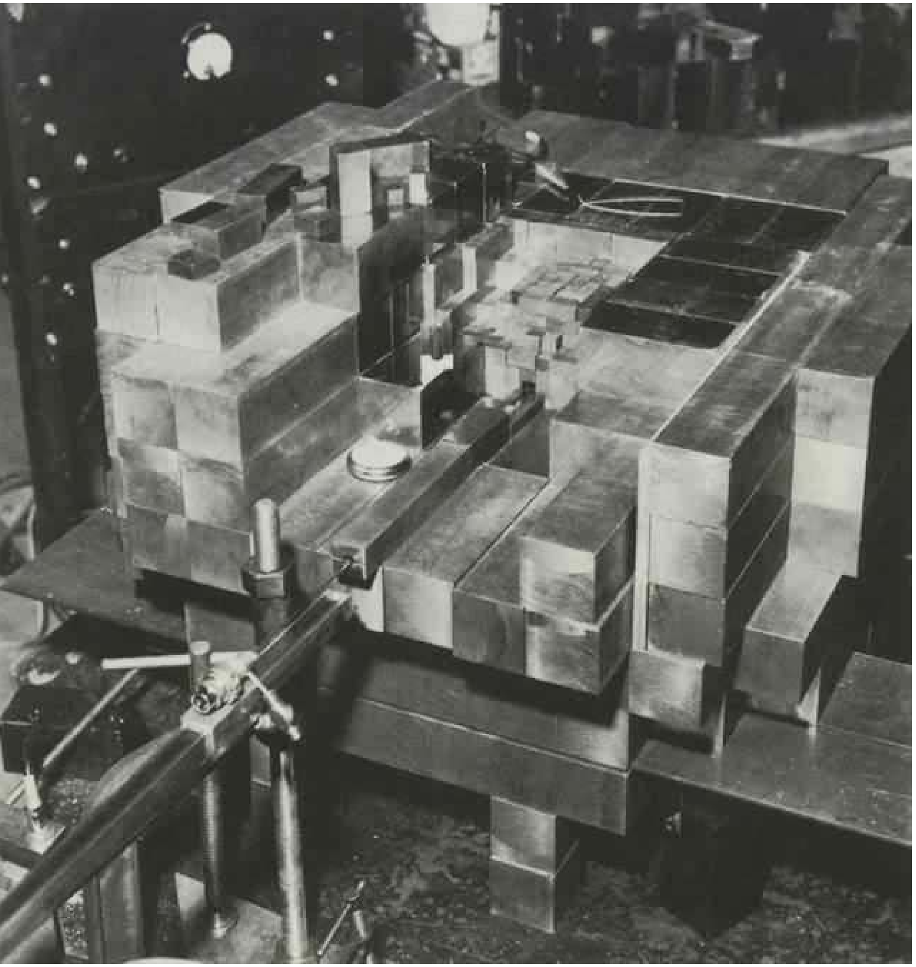
The largest items were the accelerators. Oppenheimer decided that electrostatic generators (Van de Graaff accelerators), a Cockcroft-Walton machine and a good cyclotron would be required to carry on the experimental measurements that would be transferred to Los Alamos. The Harvard cyclotron was selected as the best. Also selected were the University of Illinois' Cockcroft-Walton accelerator and two Van de Graaff accelerators at the University of Wisconsin: the "long tank," a 22ft long machine and the "short tank," a 17ft long machine.


Electrostatic accelerators

Military or Academic Environment?

Initial plan of “military laboratory” with scientists in uniform failed on refusal of academics which were to be recruited. Final agreement Between Oppenheimer and Groves was academic environment with Oppenheimer as scientific director (Robert Bacher from Cornell (& MIT) would head the experimental section, Hans Bethe (Cornell) the theory (T) division. The ultimate authority over the laboratory, however, would be the Military Policy Committee under General Groves.

Tickling the Tail of the Dragon



The determination of the critical mass for explosion

The exact size of the critical mass was determined by Otto Frisch at Los Alamos. The important input parameters were the fission cross Sections which were measured in accelerator based experiments.

Other parameters were the average neutron yield upon fission, and the mass density which depended on lattice structure of metal and the purity of the available material (absorption of neutrons).

The critical mass?

Depended of neutron flux and neutron release time versus explosion time scale

$$20\,ktons\,TNT = 8.4 \cdot 10^{13}\ J$$

$$1\ fission \equiv 3.2 \cdot 10^{-11}\ J$$

$$number\ of\ \ fissions : N = \frac{8.4 \cdot 10^{13}\ J}{3.2 \cdot 10^{-11}\ J} = 2.6 \cdot 10^{24}$$

$$235g = 6.02 \cdot 10^{23}\,atoms$$

$$m_{^{235}U} = \frac{235\,g \cdot 2.6 \cdot 10^{24}}{6.02 \cdot 10^{23}} = 1.015\,kg$$

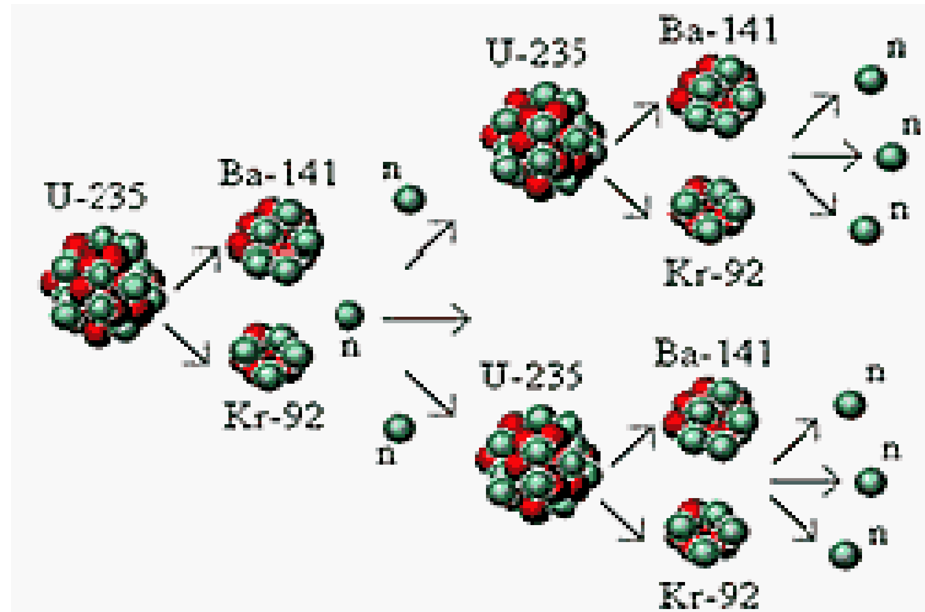
with 10% efficiency
10 kg was estimated.

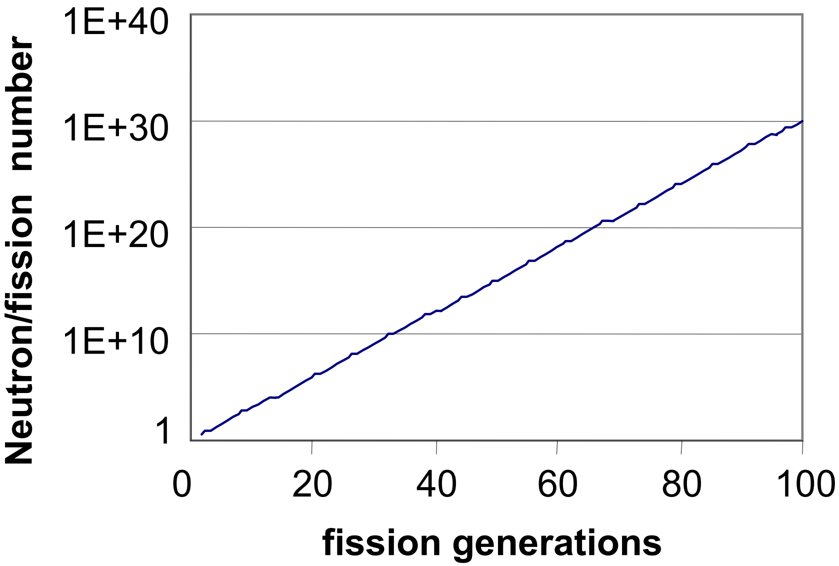
Neutron production for chain reaction

$$N_n = N_0 \cdot e^{(1-k)n}$$

$$N_0 = 1; k = 1.693$$

$$N_n = N_0 \cdot e^{0.693n} \approx 2^n$$





Neutron production factor: *k=1.63* is due to neutron absorption in material impurities (^{238}U)! In $n \approx 80$ fission generations 10^{24} neutrons for fissions have been produced.

Timing of explosion

Typical neutron velocity: *$v=10^7$ m/s*

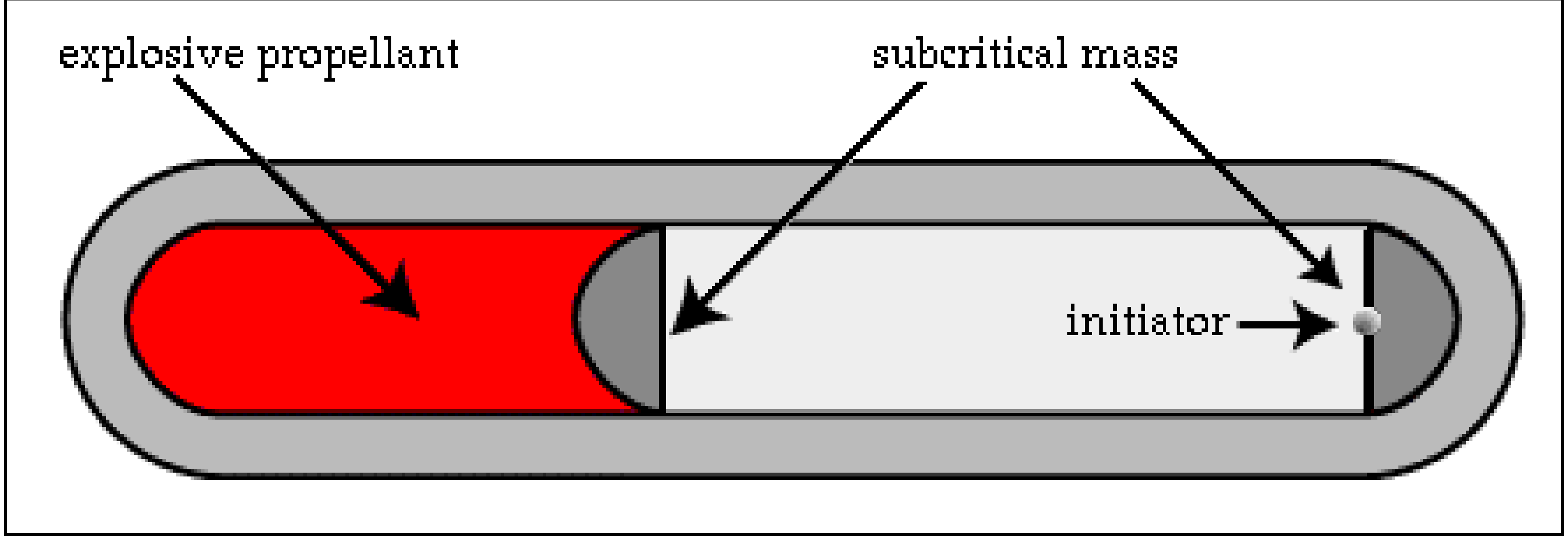
Timing for one generation is travel time of neutrons across Uranium mass with density: $\rho=1.87\cdot 10^4\ kg/m^3$.

$$\rho = \frac{M}{V} \quad V = \frac{4}{3}\pi \cdot r^3$$

$$\rho = \frac{3M}{4\pi \cdot r^3} \quad r = \left(\frac{3M}{4\pi \cdot \rho}\right)^{1/3} = 0.05m$$

$$t = \frac{2 \cdot r}{v} = 10^{-8}\ s$$

For ~80 generations ~1μs
Mass must remain confined for ~1μs
since most of the energy production
takes place during last 10 generations



Gun Design

- This design worked with uranium.
- A 2000 lb TNT Blockbuster bomb was used as the “trigger” to bring critical mass together.

Gun - Triggered Fission Bomb

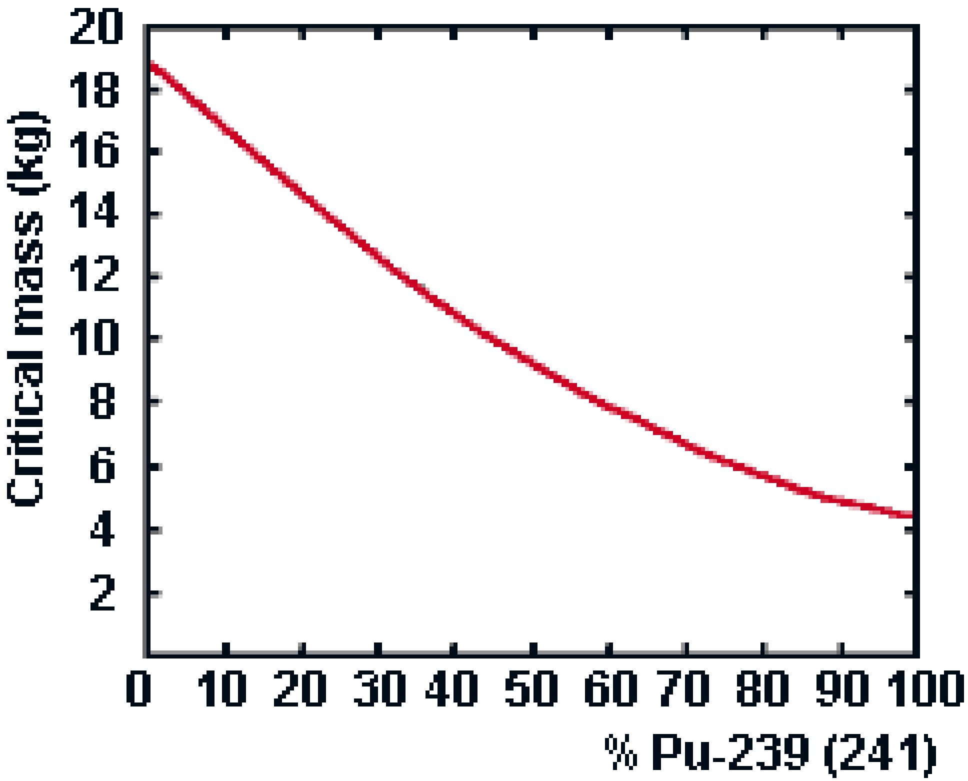
Length:	10 feet 6 inches
Diameter:	29 inches
Weight:	9,700 lbs
Yield:	14.5 kilotons

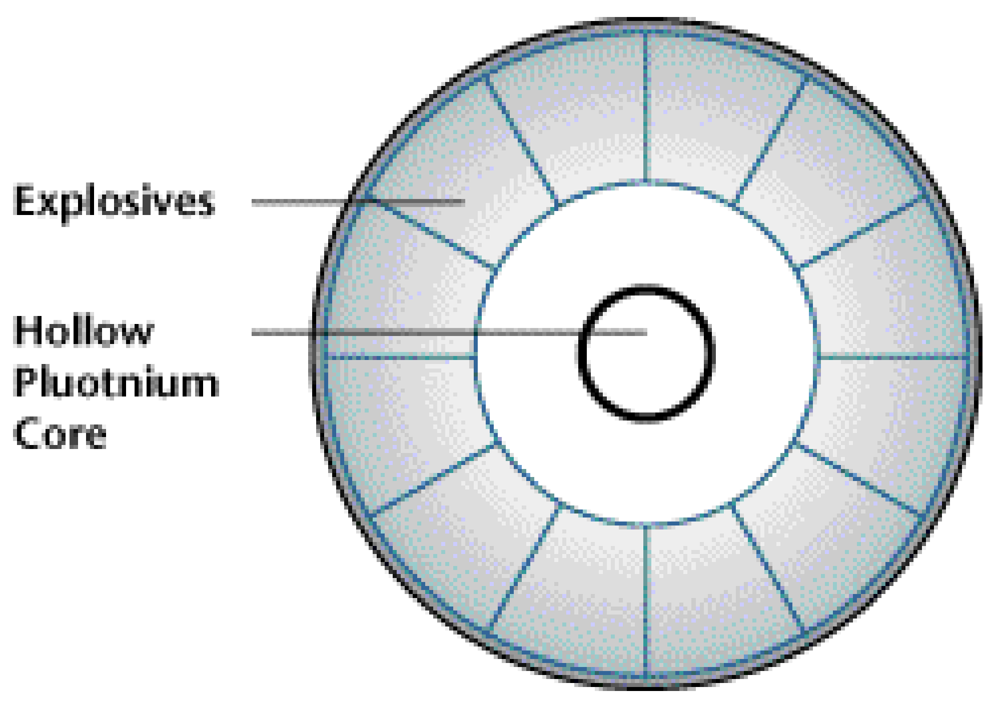
Remove Shell

a.k.a. -
"Little Boy"

Plutonium device

Without a neutron reflecting shield, pure Pu-239 metal has a critical mass of **10 kg**, for a "reactor grade" isotopic mixture this would be 18 kg. Using a 15 cm U-238 shield, the Pu-239 critical mass is only some **4 kg**, while for LWR-produced plutonium this is some **7 kg**.





Fat Man Schematic

Implosion Design

- This design was required for plutonium.
- Impurities of ^{240}Pu (produced by secondary ^{239}Pu(n,γ)^{240}Pu reactions) would release too many neutrons and cause premature detonation in the gun design before optimum critical conditions are reached. This would lower the yield.
- This design needed testing ⇨ Trinity test

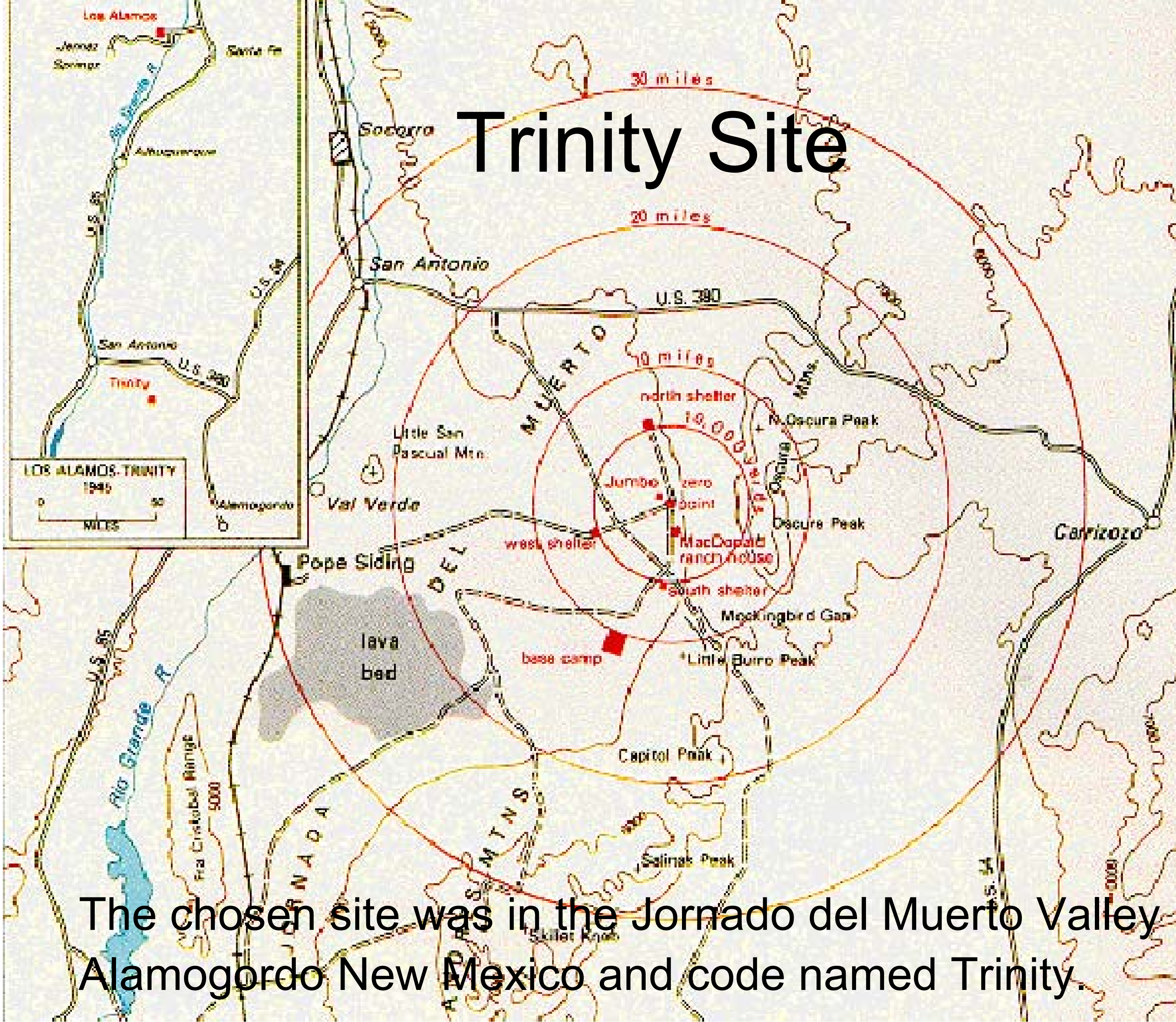
Implosion - Triggered Fission Bomb

Length:	10 feet 8 inches
Diameter:	5 feet
Weight:	10,000 lbs
Yield:	23 kilotons

Remove Shell

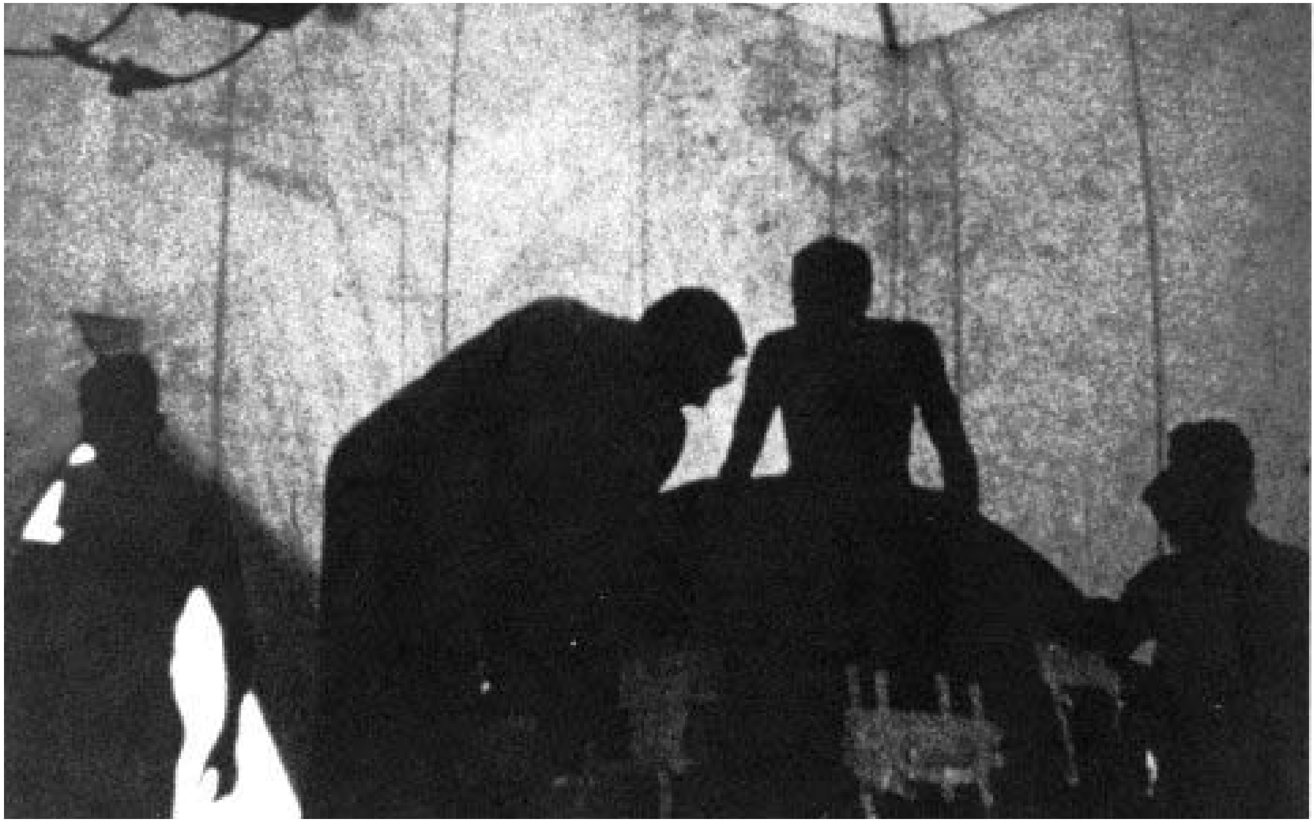
a.k.a. - "Fat Man"

Trinity Site



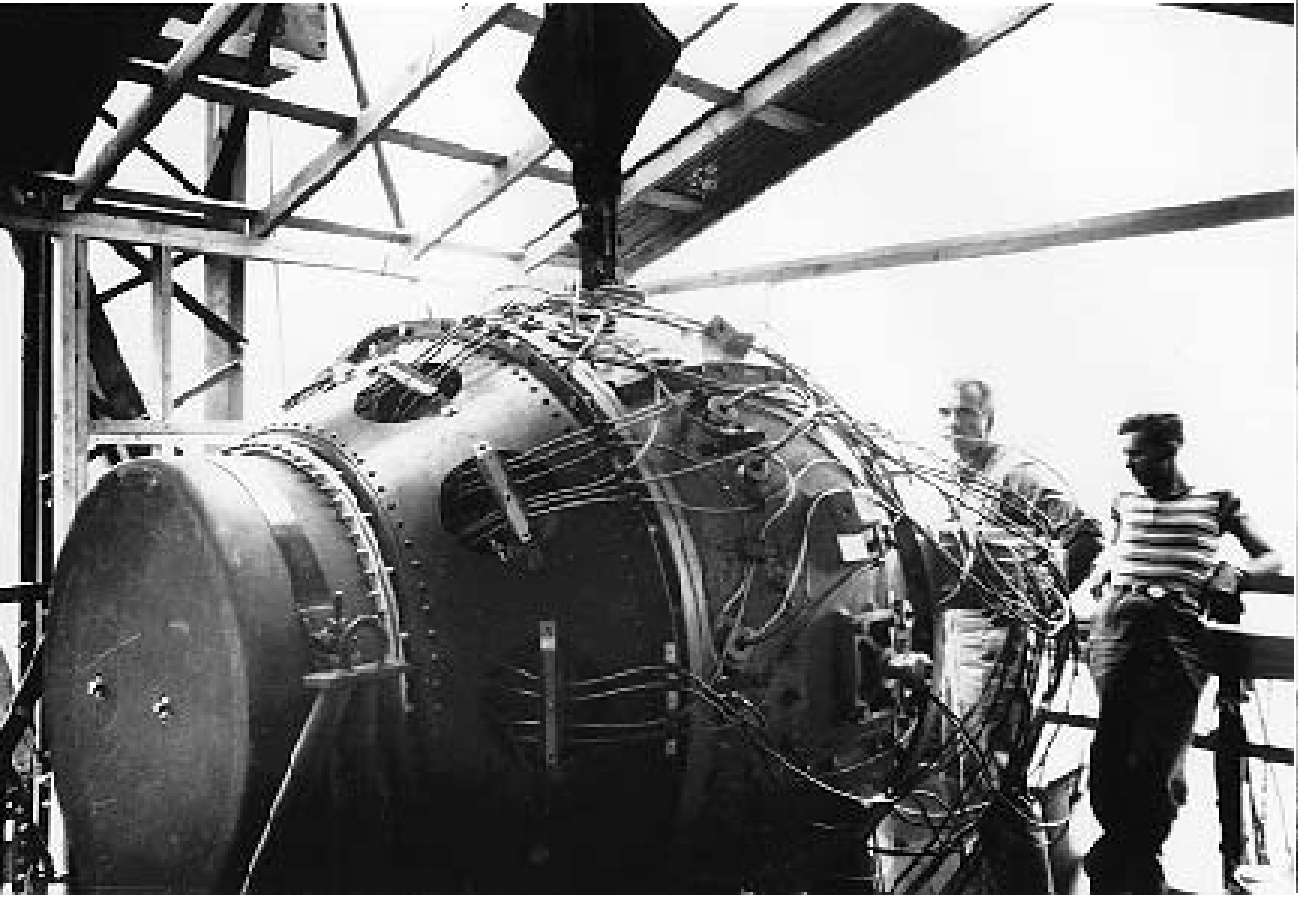
The chosen site was in the Jornado del Muerto Valley near Alamogordo New Mexico and code named Trinity.

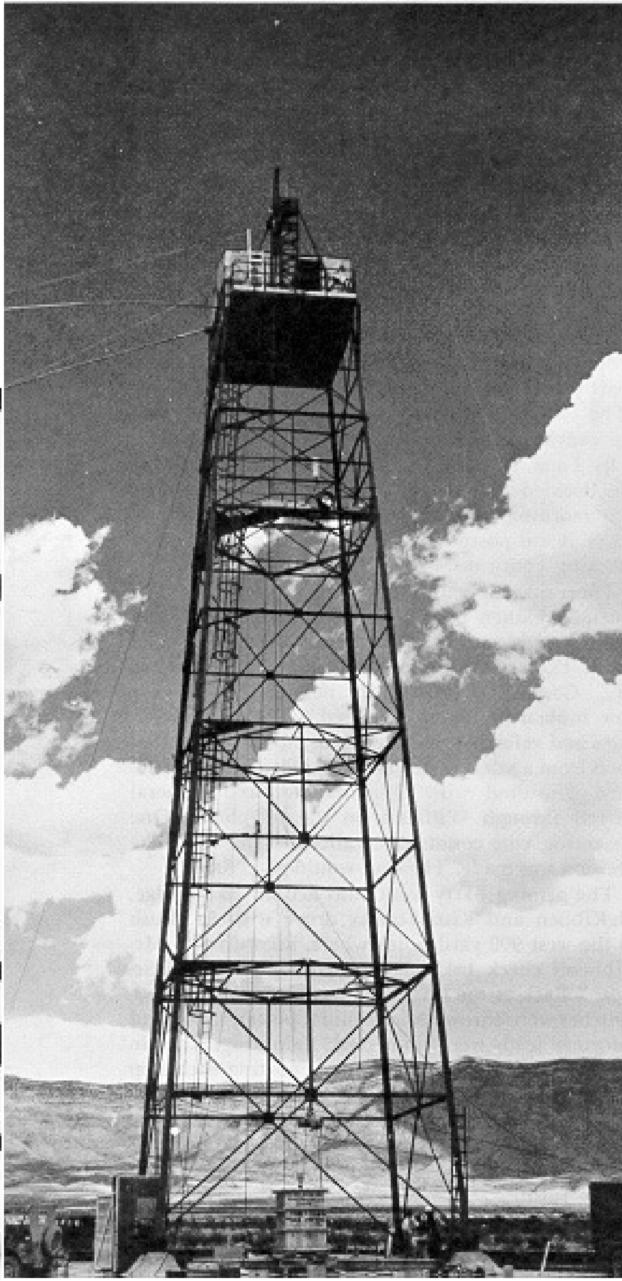
The set-up of the Trinity test



The loading of the Plutonium into the “Gadget”

Gadget

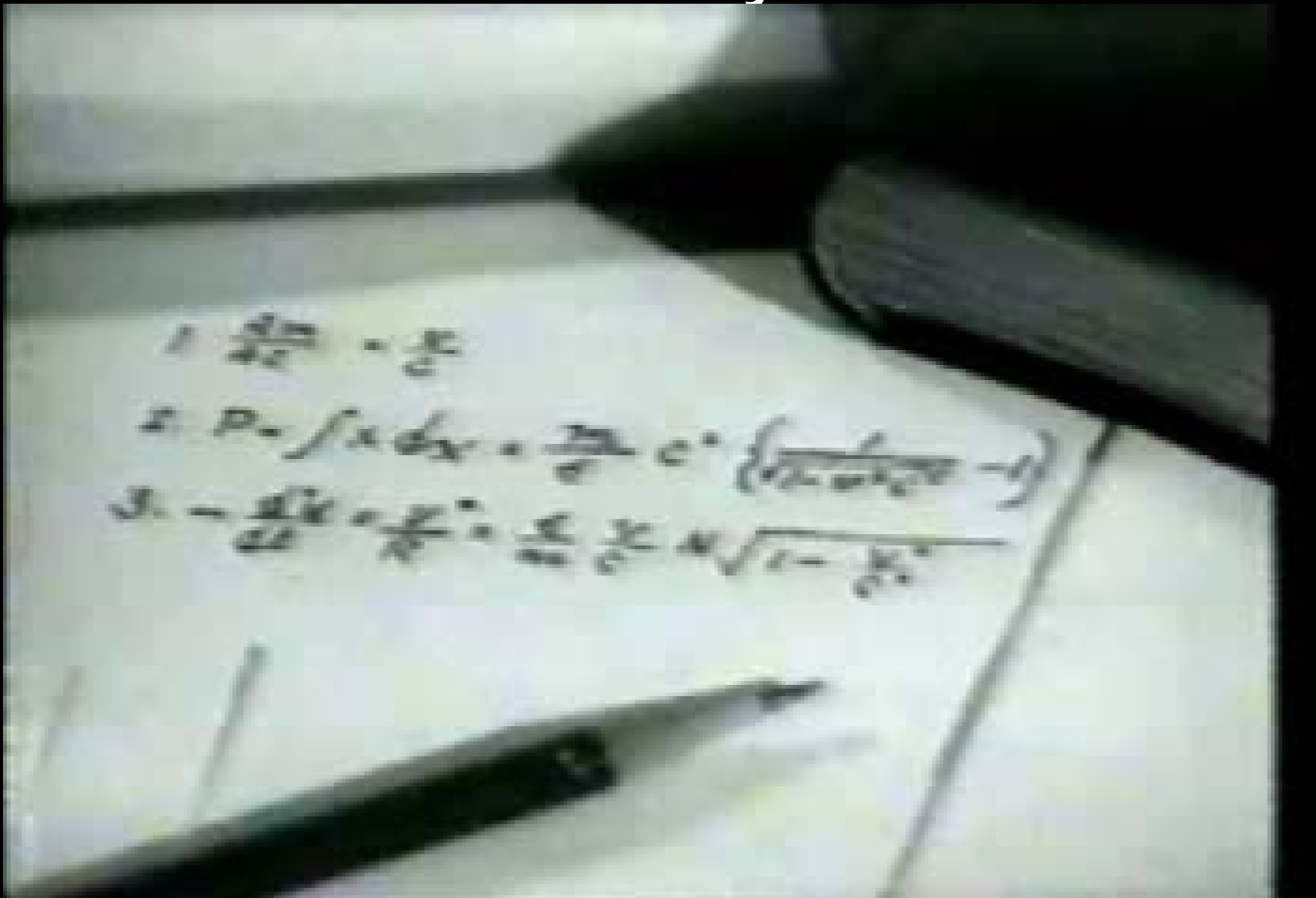




The Dawn of the Nuclear Age

The first nuclear explosion occurred at 5:29:45 am on July 16, 1945 at Trinity site.

Trinity



- Edward Teller described wearing double welders glasses and was not impressed until he removed his hands from around the glasses.
- Fermi was holding pieces of paper in his hand and waited for the shock wave to estimate the output. He later commented on missing both fission and the first nuclear explosion.

National Success Story?

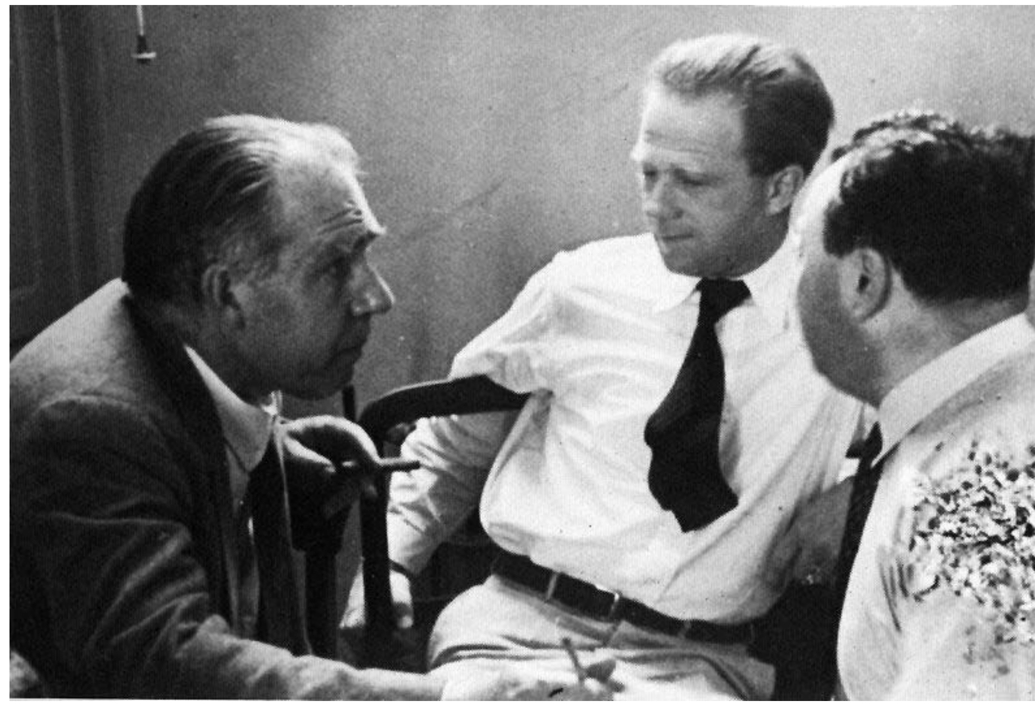
International effort,

Hans Bethe,	Leo Szilard,
Niels Bohr	Edgar Teller
Enrico Fermi,	Georg Uhlenbeck
Otto Frisch	Stansilav Ulam
Klaus Fuchs,	Victor Weisskopf
Georg Gamow	Eugene Wigner

Trinity Summary

How were the Germans doing?

Meeting between Bohr & Heisenberg in Copenhagen
in September 1941



Looking for help?
Passing on information?
Boasting of progress?

Heisenberg maintained claim that he was working on reactor not bomb design! He was officially head of the German Uranium club.

1942 first reactor design in Leipzig
1943 cancellation of Uranium bomb project
1944 reactor in Haigerloch – remained too small!

The critical mass from German view

The best evidence we have suggests that Heisenberg had no interest in building an atomic bomb. In mid-1942, Albert Speer, the weapons minister, asked Heisenberg whether he could produce a weapon in nine months. With a clear conscience he could answer "No." And he did not know how much fissionable material he would need. When, on occasion, friends asked him, his replies were varied and vague, ranging from 10 kilograms to a few tons.

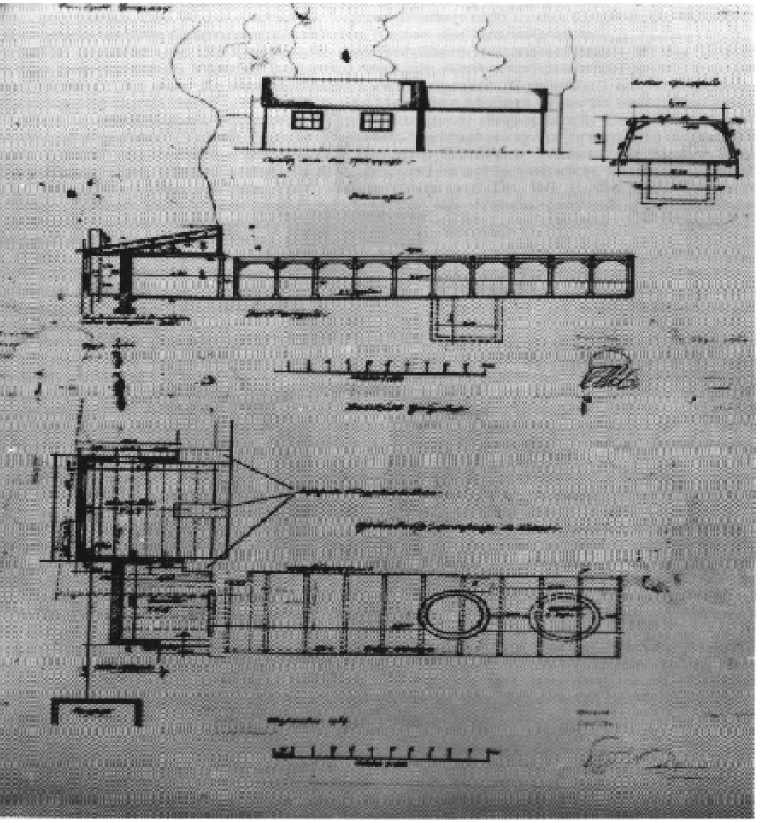
Why didn't he know? Why hadn't pure intellectual curiosity led him to investigate the properties of uranium-235 with fast neutrons? He could have made a small amount using the cyclotrons available in both Paris and Copenhagen. But he never asked that these properties be measured. The best proof of his lack of interest came at the end of the war. Heisenberg and about ten other German nuclear scientists were interned at Farm Hall, a country estate in England. … His first attempt at explanation (*of the Hiroshima bomb*) was totally wrong! He hypothesized something like a nuclear reactor, with the neutrons slowed by many collisions with a moderator.

That he was capable of doing the work was shown about a week later when, in another lecture, he corrected himself and presented a theory similar to that worked out by Rudolf Peierls and Otto Frisch in 1940. He estimated the necessary amount of uranium-235 at about 20 kg, which is nearly correct.

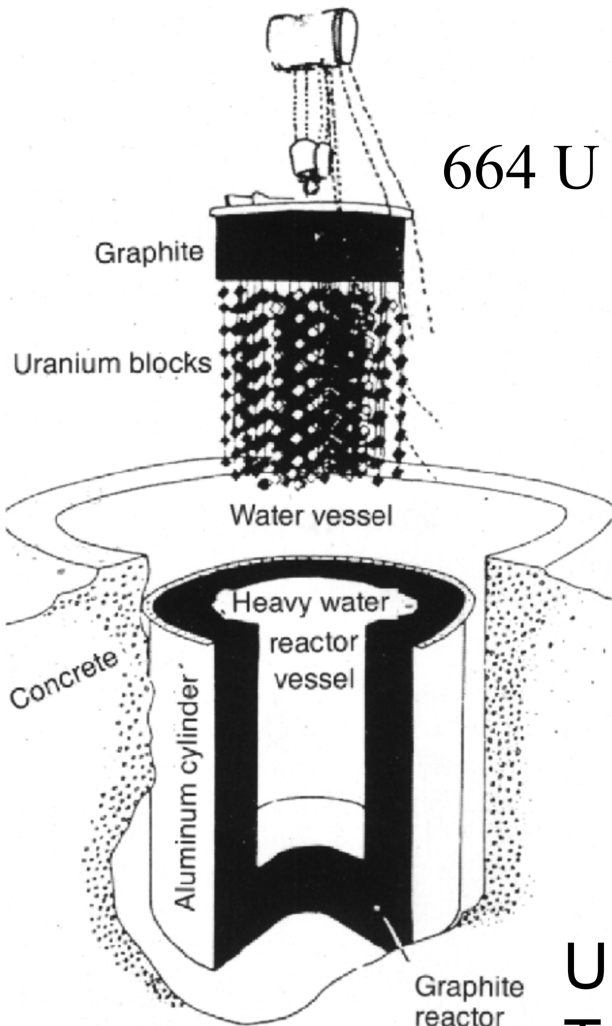
Hans Bethe in Physics Today Vol 53 (2001)

Indications for activity

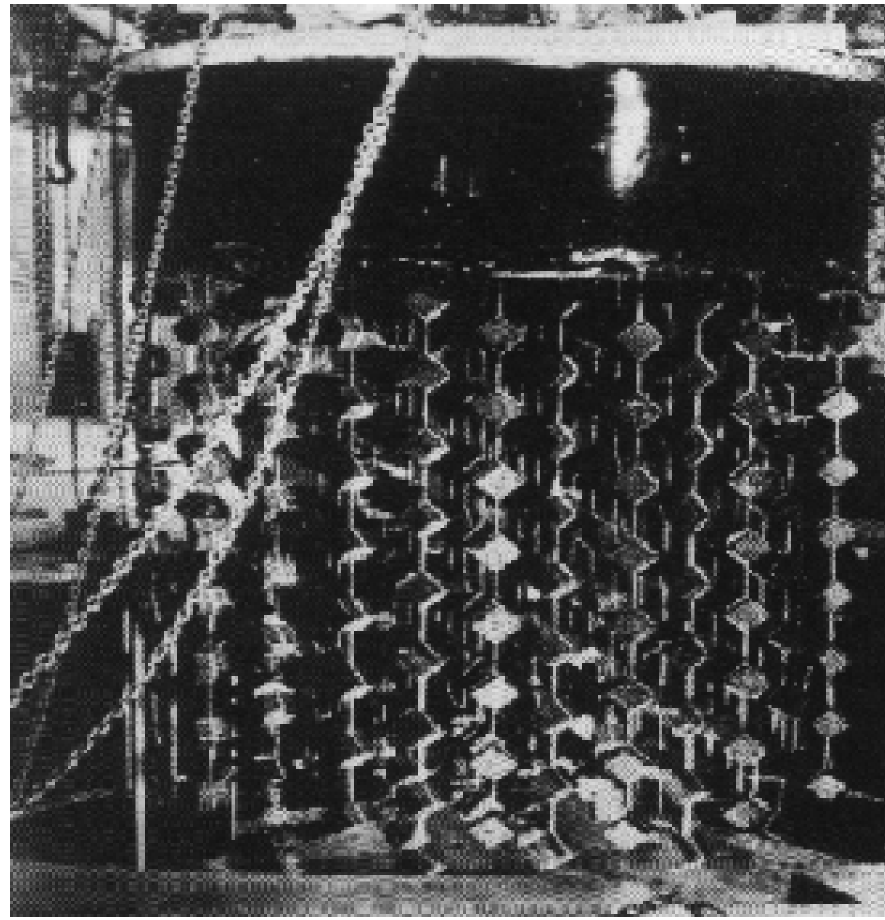
Used French cyclotron accelerator of Joliot-Curie
Maintained studies of moderator systems (Walter Bothe)
Continued reactor research



The German Reactor B8 in Haigerloch



664 U cubes



Uranium blocks immersed in heavy water
Too small on neutron enhancement factor 7

The Alsos Mission in Haigerloch

The end of the German nuclear program

Lucky guys!


NAZIS GIVE UP!

THE DEPAUW

German Surrender May 7. 1945


HUNS CAME CL[illegible] TO DESTROYING EARTH, SAYS AGAR

(By Associated Press.)

Commander Herbert Agar, aide to United States ambassador to Great Britain John G. Winant, said on June 29 that "if the war (European) had gone on for another six months, it is quite possible that this planet would have ceased to exist because it was probable that someone would have learned to break the atom without controlling it."

Agar said "there was a danger that the Germans would learn how to split the atom first," and added: "I sincerely believe that in a very few years human beings will know how to destroy the human race."

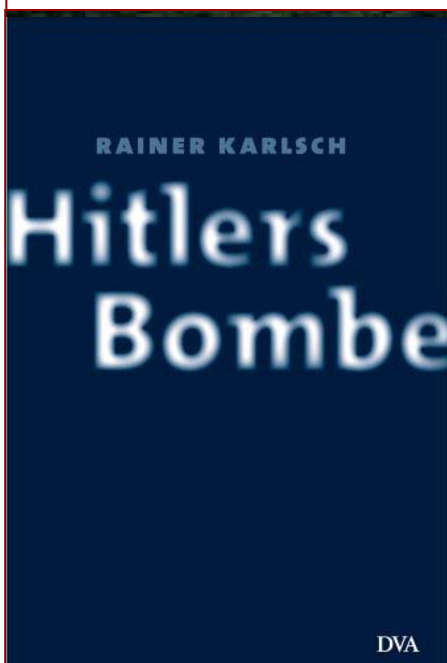
Was there a nuclear race?

- Did German scientists fail to recognize opportunity?
- Did Bothe stop program by mistake in moderator calculation?
- Did Heisenberg fail (initially) in calculating critical mass?
- Did allied air raids successfully stop German nuclear attempts?
- Did lack of Hitler support stop nuclear weapons program?
- or combination of all these points?

New Evidence?
A German Bomb after all?

BBC NEWS WORLD EDITION

A German historian has claimed in a new book presented on Monday that Nazi scientists successfully tested a tactical nuclear weapon in the last months of World War II.



"It was about 9:30 when I suddenly saw something ... it was as bright as hundreds of bolts of lightning, red on the inside and yellow on the outside, so bright you could've read the newspaper. It all happened so quickly, and then we couldn't see anything at all. We just noticed there was a powerful wind..." The woman complained of "nose bleeds, headaches and pressure in the ears."

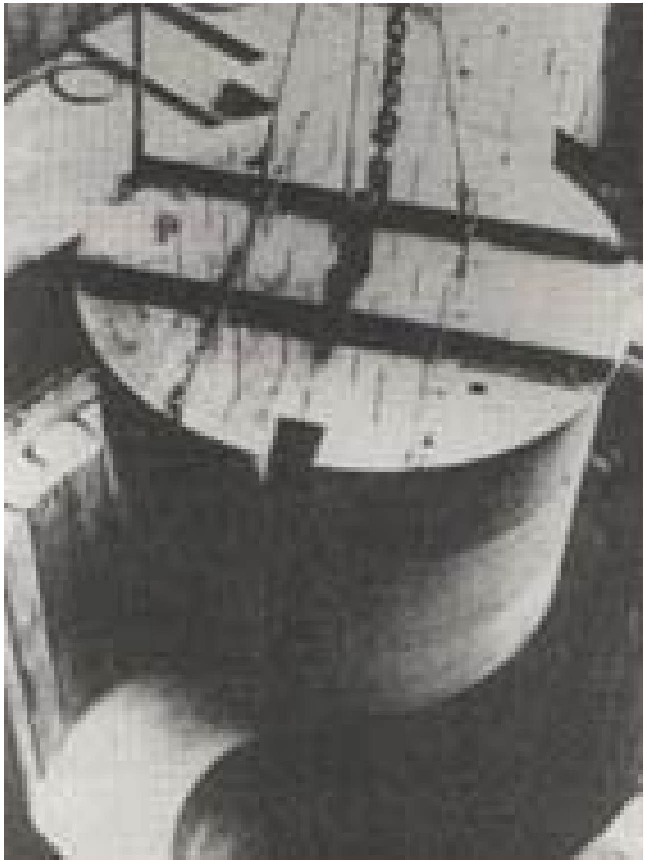
The next day Heinz Wachsmut, a man who worked for a local excavating company, was ordered to help the SS build wooden platforms on which the corpses of prisoners were cremated. The bodies, according to Wachsmut, were covered with horrific burn wounds. Like Werner, Wachsmut reports that local residents complained of headaches, some even spitting up blood.

In Wachsmut's account, higher-ranking SS officers told people that something new had been tested, something the entire world would soon be talking about.

Gruppe Kurt Diebner

Kurt Diebner, Director of the Heeresversuchsanstalt

(Experimental research group of German army)



Supported by Walter Gerlach, new head of the Uranium Club since 1944

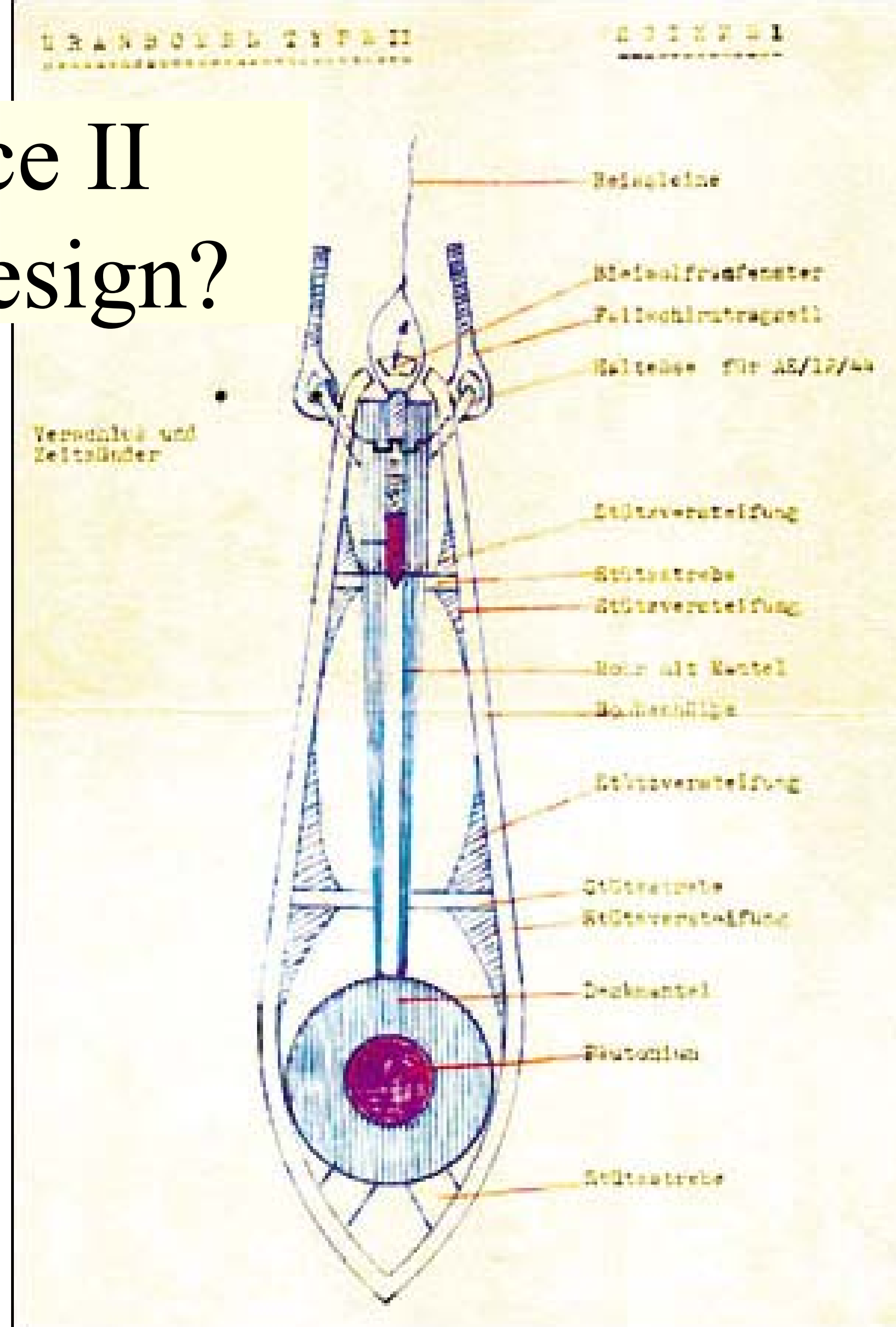
Supporting evidence I
1941 Patent by v. Weizsäcker

Von Weizsäcker wrote a patent application of 1941, which was found in Russian archives. The draft shows that he did indeed understand both the properties and the military applications of plutonium. "The production of element 94 [i.e. plutonium] in practically useful amounts is best done with the 'uranium machine' [nuclear reactor]," the application states. "It is especially advantageous - and this is the main benefit of the invention - that the element 94 thereby produced can easily be separated from uranium chemically."

Von Weizsäcker also makes it clear that plutonium could be used in a powerful bomb. "With regard to energy per unit weight this explosive would be around ten million times greater than any other [existing explosive] and comparable only to pure uranium 235," he writes. Later in the patent application, he describes a "process for the explosive production of energy from the fission of element 94, whereby element 94...is brought together in such amounts in one place, for example a bomb, so that the overwhelming majority of neutrons produced by fission excite new fissions and do not leave the substance".

Supporting Evidence II
a German Bomb Design?

An undated (~60 year old) report was found in private archives. The author is unknown. The report contains a diagram which seems to give evidence of a German plutonium bomb design near the end of the war in Europe. Production site of Plutonium?



Failure of the German Bomb Project

Recent evidence shows that the physics was understood. The technical know expertise was available, but the project failed because of compartmentalization of the efforts, Uranium Club, Heeresforschungsgruppe, SS initiatives and several other institutions performed independent uncoordinated research. US advantage was the development of a concerted and coordinated research effort, the Manhattan Project.

Hiroshima & Nagasaki

From Roosevelt to Truman

Roosevelt dies on April 12, 1945 in Warm Springs, Georgia. Vice President Harry S Truman is sworn in.

Truman is out of the loop and does not know about the atomic bomb. He is the one to decide if it should be used, and when. The atomic scientists, driven by the possibility of a Nazi bomb, begin to debate the morality of using the bomb in combat.

Truman has no such moral complications. The election of 1944 was characterized by the realization the American public is tired of war, and if he had a wizard weapon and failed to use it, he might be impeached.

In Washington, the use of the bomb is never questioned. Targets are set aside, preserving them to test the full power of the bomb.

German Unconditional Surrender! A Missed Opportunity!

In spring 1945 it became obvious that project would not be ready before Germany’s collapse. That triggered discussion of plan modifications.

- ❑ Should the bomb be used for Japan?
- ❑ Is bomb use justified like it seemed justified for Germany?
- ❑ Would the scientists continue their work with new goal?

Hans Bethe, who headed the Theoretical Division at Los Alamos, was astonished Groves presented the situation and new plans in February:

"I am amazed both by the conclusion not to use [the bomb] on Germany and secondly by their reasons [for targeting the Japanese fleet]. We [the scientists] had no idea of such a decision. We were under the impression that Germany was the first target until the German surrender. That was my belief. Obviously, it was wrong."

Opportunities & Alternatives?

Definition of new goal for demonstrating new weapon:
Forcing Japanese unconditional surrender to avoid extended jungle war and invasion of Japanese islands

To Use or Not to Use?

Japan had never been a threat to develop a bomb.
General Groves definitely wanted to use the bombs.
This triggered discussion in bomb development community:

Target Committee, Los Alamos, May 10-11, 1945 – Identified bombing conditions and four possible target sites in Japan; **Kyoto** (old capital), **Hiroshima** (urban industrial area), **Yokohama** (industrial center), **Kokura Arsenal** (military industrial complex)

The Franck Report, June 11, 1945 - The Franck Report, written by a seven-man panel of scientists at the University of Chicago, urged that the bomb be demonstrated "before the eyes of representatives of all United Nations, on the desert or a barren island.“

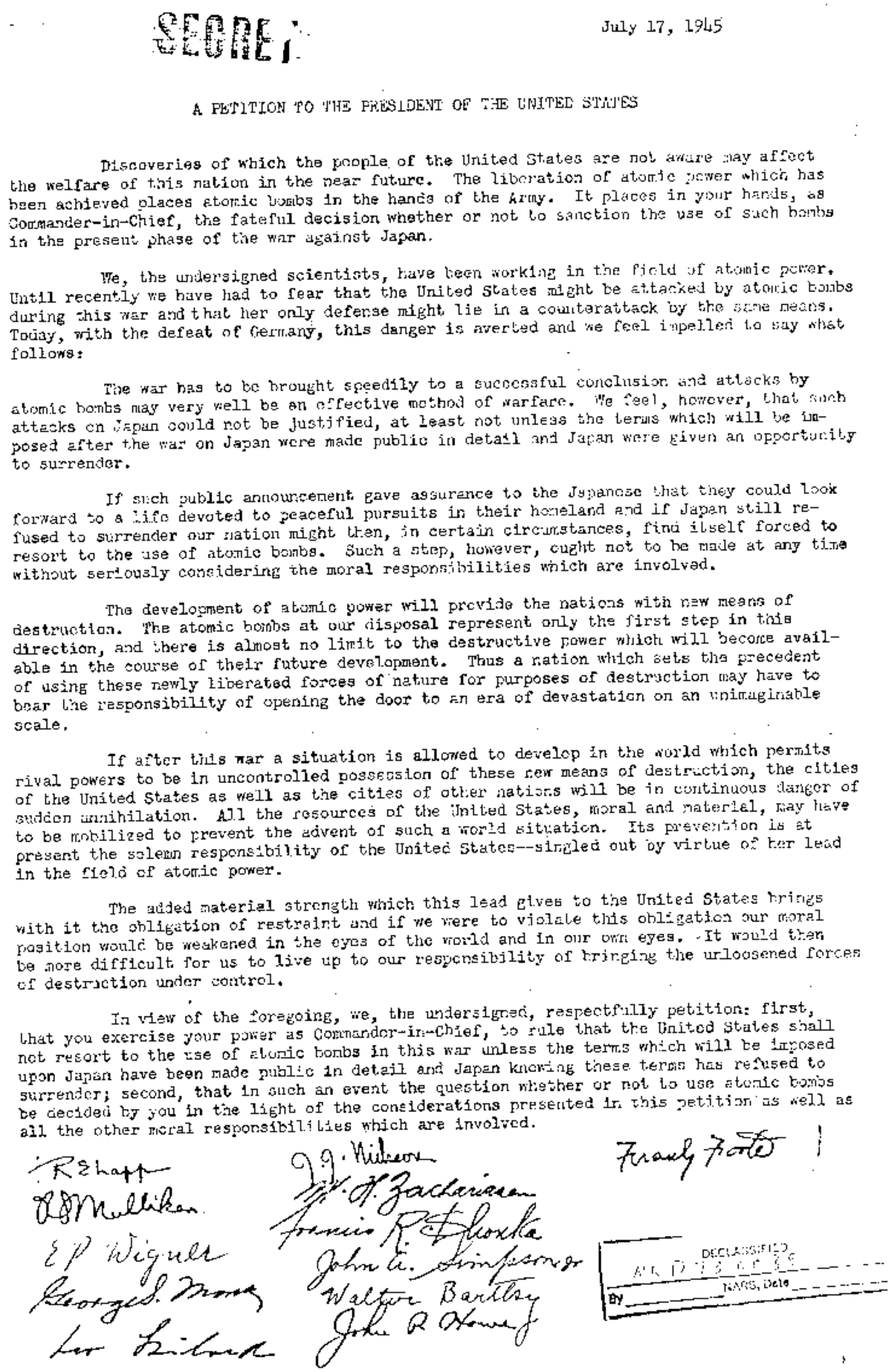
Scientific Panel, June 16, 1945 - Despite the arguments against using the bomb made by the Franck Report, a panel composed of Oppenheimer, Fermi, Compton, and Lawrence found "no acceptable alternative to direct military use."

Target Identification

The Szilard petition

Groves Seeks Evidence, July 4, 1945 – As Szilard prepared a petition to the president calling atomic bombs "a means for the ruthless annihilation of cities.", General Groves sought ways to take action against him, considered charging Szilard with violating the Espionage Act.

Szilard Petition, July 17, 1945 – Leo Szilard, and 69 co-signers at the Manhattan Project "Metallurgical Laboratory" in Chicago, petitioned the President of the United States against the use of the bomb. Several petitions from scientists at Los Alamos and Oak Ridge followed.



SECRET

July 17, 1945

A PETITION TO THE PRESIDENT OF THE UNITED STATES

Discoveries of which the people of the United States are not aware may affect the welfare of this nation in the near future. The liberation of atomic power which has been achieved places atomic bombs in the hands of the Army. It places in your hands, as Commander-in-Chief, the fateful decision whether or not to sanction the use of such bombs in the present phase of the war against Japan.

We, the undersigned scientists, have been working in the field of atomic power. Until recently we have had to fear that the United States might be attacked by atomic bombs during this war and that her only defense might lie in a counterattack by the same means. Today, with the defeat of Germany, this danger is averted and we feel impelled to say what follows:

The war has to be brought speedily to a successful conclusion and attacks by atomic bombs may very well be an effective method of warfare. We feel, however, that such attacks on Japan could not be justified, at least not unless the terms which will be imposed after the war on Japan were made public in detail and Japan were given an opportunity to surrender.

If such public announcement gave assurance to the Japanese that they could look forward to a life devoted to peaceful pursuits in their homeland and if Japan still refused to surrender our nation might then, in certain circumstances, find itself forced to resort to the use of atomic bombs. Such a step, however, ought not to be made at any time without seriously considering the moral responsibilities which are involved.

The development of atomic power will provide the nations with new means of destruction. The atomic bombs at our disposal represent only the first step in this direction, and there is almost no limit to the destructive power which will become available in the course of their future development. Thus a nation which sets the precedent of using these newly liberated forces of nature for purposes of destruction may have to bear the responsibility of opening the door to an era of devastation on an unimaginable scale.

If after this war a situation is allowed to develop in the world which permits rival powers to be in uncontrolled possession of these new means of destruction, the cities of the United States as well as the cities of other nations will be in continuous danger of sudden annihilation. All the resources of the United States, moral and material, may have to be mobilized to prevent the advent of such a world situation. Its prevention is at present the solemn responsibility of the United States--singled out by virtue of her lead in the field of atomic power.

The added material strength which this lead gives to the United States brings with it the obligation of restraint and if we were to violate this obligation our moral position would be weakened in the eyes of the world and in our own eyes. It would then be more difficult for us to live up to our responsibility of bringing the unloosened forces of destruction under control.

In view of the foregoing, we, the undersigned, respectfully petition: first, that you exercise your power as Commander-in-Chief, to rule that the United States shall not resort to the use of atomic bombs in this war unless the terms which will be imposed upon Japan have been made public in detail and Japan knowing these terms has refused to surrender; second, that in such an event the question whether or not to use atomic bombs be decided by you in the light of the considerations presented in this petition as well as all the other moral responsibilities which are involved.

R E Lapp
R S Mulliken
E P Wigner
George S. Monk
Leo Szilard
J. J. Nickson
W. H. Zachariasen
Francis R. Shonka
John A. Simpson Jr
Walter Bartky
John R Howe
Frank Foote

DECLASSIFIED
NARS, Date
BY

Leo Szilard Home Page - World-Wide Web - http://www.peak.org/~danneng/szilard.html

Bombing Civilian Targets

By all international law, the bombing of civilians was regarded as a barbaric act!

President Roosevelt on Aerial Bombardment of Civilian Populations,
The President of the United States to the Governments of
France, Germany, Italy, Poland and His Britannic Majesty,
September 1, 1939

The ruthless bombing from the air of civilians in unfortified centers of population during the course of the hostilities which have raged in various quarters of the earth during the past few years, which has resulted in the maiming and in the death of thousands of defenseless men, women, and children, has sickened the hearts of every civilized man and woman, and has profoundly shocked the conscience of humanity.

I am therefore addressing this urgent appeal to every government which may be engaged in hostilities publicly to affirm its determination that its armed forces shall in no event, and under no circumstances, undertake the bombardment from the air of civilian populations or of unfortified cities, upon the understanding that these same rules of warfare will be scrupulously observed by all of their opponents. I request an immediate reply. FRANKLIN D. ROOSEVELT

Bard Memorandum, June 27, 1945 - Undersecretary of the Navy Ralph A. Bard wrote that use of the bomb without warning was contrary to "the position of the United States as a great humanitarian nation," especially since Japan seemed close to surrender.

The Potsdam Declaration

Proclamation Defining Terms for Japanese Surrender
Issued, at Potsdam, July 26, 1945

1 We-the President of the United States, the President of the National Government of the Republic of China, and the Prime Minister of Great Britain, representing the hundreds of millions of our countrymen, have conferred and agree that Japan shall be given an opportunity to end this war.

.
.
.

13 We call upon the government of Japan to proclaim now the **unconditional surrender** of all Japanese armed forces, and to provide proper and adequate assurances of their good faith in such action. The alternative for Japan is prompt and utter destruction.

Only obstacle for Japanese acceptance the term "**unconditional surrender**"
Meaning humiliation, loss of face, loss of emperor, loss of Japanese soul.

Political Discussions

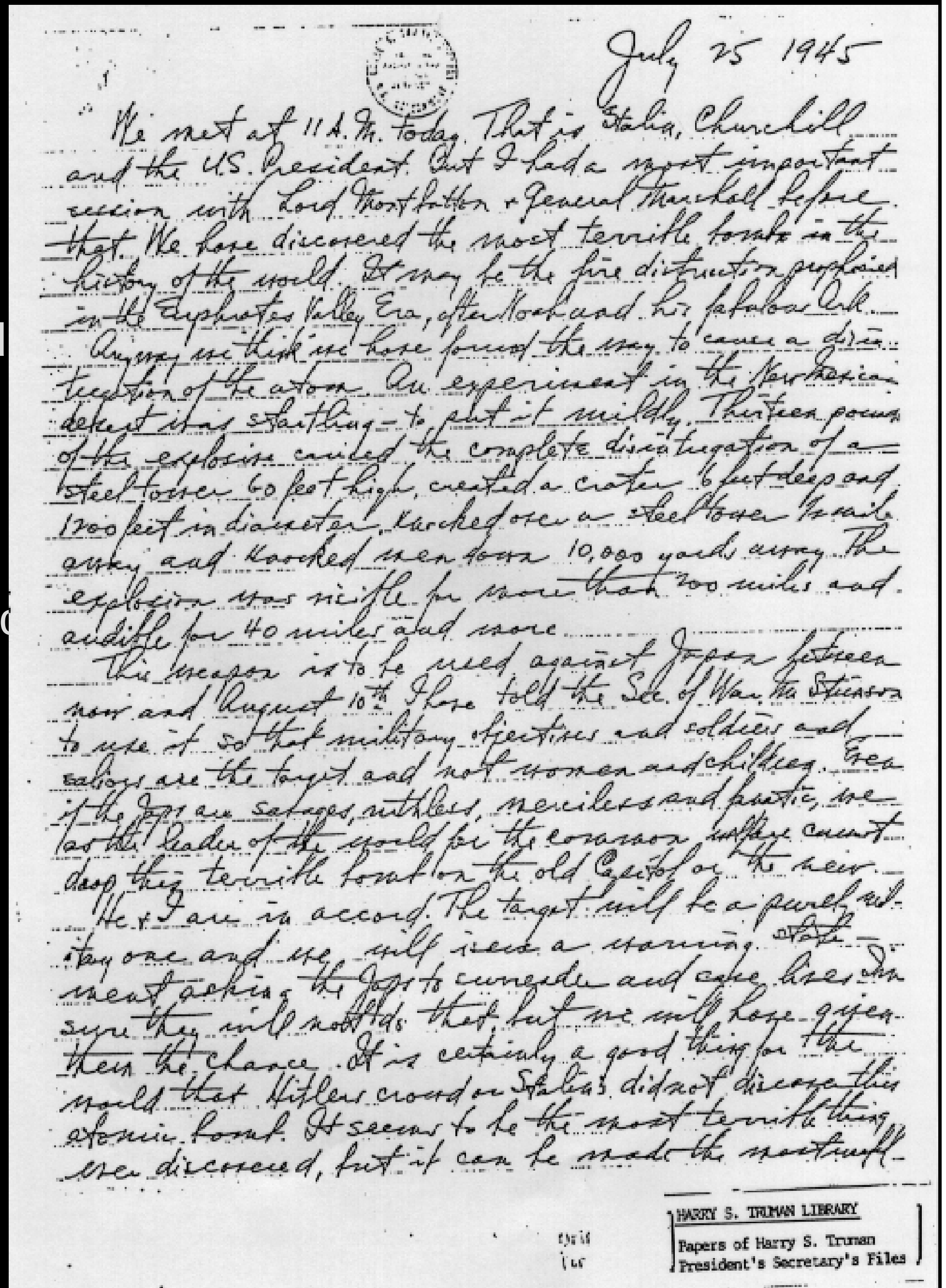
Setting the Test Date, July 2, 1945 - President Truman had delayed his meeting with Stalin until the atomic bomb could be tested. On July 2, General Groves told Robert Oppenheimer that the test date was being set by "**the upper crust**."

Truman Tells Stalin, July 24, 1945 - At the Potsdam Conference in defeated Germany, President Truman told Stalin only that the U.S. "**had a new weapon of unusual destructive force**."

The Decision

Truman Diary, July 25, 1945 –
President Truman told his diary that he had ordered the bomb dropped on a "purely military" target, so that "military objectives and soldiers and sailors are the target and not women and children. Even if the Japs are savages, ruthless, merciless and fanatic we as the leader of the world for the common welfare cannot drop that terrible bomb on the old capital or the new. The **target will be a purely military one!**

Official Bombing Order, July 25, 1945 –
The bombing order issued to General Spaatz made no mention of targeting military objectives or sparing civilians. **The cities themselves were the targets.**



July 25 1945

We met at 11 A.M. today. That is, Stalin, Churchill and the U.S. President. But I had a most important session with Lord Mountbatten & General Marshall before that. We have discovered the most terrible bomb in the history of the world. It may be the fire destruction prophesied in the Euphrates Valley Era, after Noah and his fabulous Ark.

Anyway we think we have found the way to cause a disintegration of the atom. An experiment in the New Mexican desert was startling—to put it mildly. Thirteen pounds of the explosive caused the complete disintegration of a steel tower 60 feet high, created a crater 6 feet deep and 1200 feet in diameter, knocked over a steel tower 1/2 mile away and knocked men down 10,000 yards away. The explosion was visible for more than 200 miles and audible for 40 miles and more.

This weapon is to be used against Japan between now and August 10th. I have told the Sec. of War, Mr. Stimson to use it so that military objectives and soldiers and sailors are the target and not women and children. Even if the Japs are savages, ruthless, merciless and fanatic, we as the leader of the world for the common welfare cannot drop this terrible bomb on the old Capitol or the new.

He & I are in accord. The target will be a purely military one and we will issue a warning statement asking the Japs to surrender and save lives. I'm sure they will not do that, but we will have given them the chance. It is certainly a good thing for the world that Hitler's crowd or Stalin's did not discover this atomic bomb. It seems to be the most terrible thing ever discovered, but it can be made the most useful.


HIROSHIMA

Mission to Hiroshima

Colonel Paul Tibbets stands next to his B-29 Superfortress, "Enola Gay" named for his mother

August 6 1945

Colonel Paul Tibbets' "Enola Gay" lands after dropping the atomic bomb on Hiroshima

Tinian, Marianas Islands
August 6, 1945

At approximately 2:00 on the morning of August 6th, the Enola Gay, which was carrying an atomic bomb (Little Boy), started on the long flight from Tinian. At about 7:00 o'clock, the Japanese radar net detected aircraft heading toward Japan, and they broadcast the alert t throughout the Hiroshima area. There was no sign of bombers. The people began their daily work since they thought that the danger had passed.

City of Hiroshima on August 5, 1945

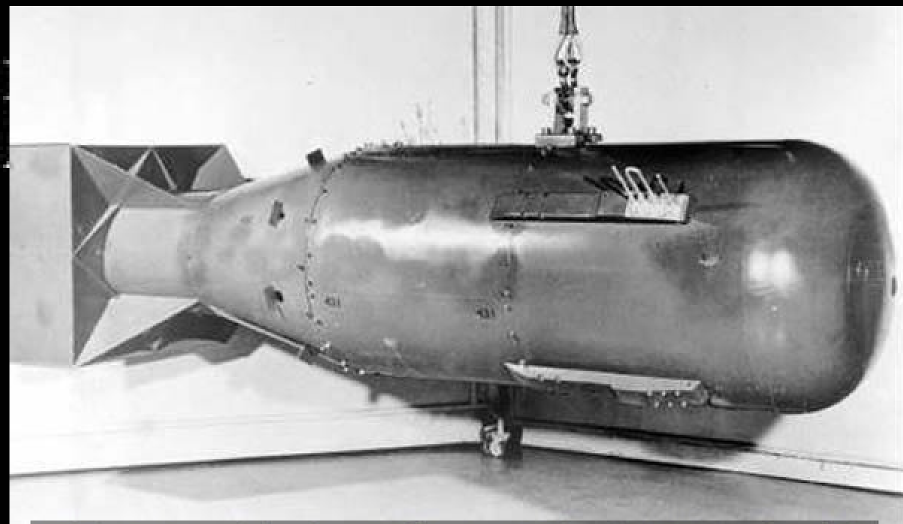
Middle size coastal city founded 1594 and built on six islands
In 1945 the city had a population of 350,000 people, served as local military command center but was mainly commercial and industry oriented around several small shipyards.

The Hiroshima Bomb

Little Boy exploded at approximately 8:15 a.m. above the “A-Bomb Dome” at an altitude of 2,000 ft.

A mushroom cloud extends 20,000 feet into the sky and 10,000 feet in diameter over the city after the first atomic attack in history.

The photo was taken by Bob Caron, tail gunner of the “Enola Gay,” the B-29 Superfortress that dropped the bomb



“Little Boy” atomic bomb — 29" diameter, 126" length, 9,700 pounds weight, 20,000 tons of TNT equivalent yield

Report of the Pilot

City of Hiroshima on August 7, 1945

Areal Devastation

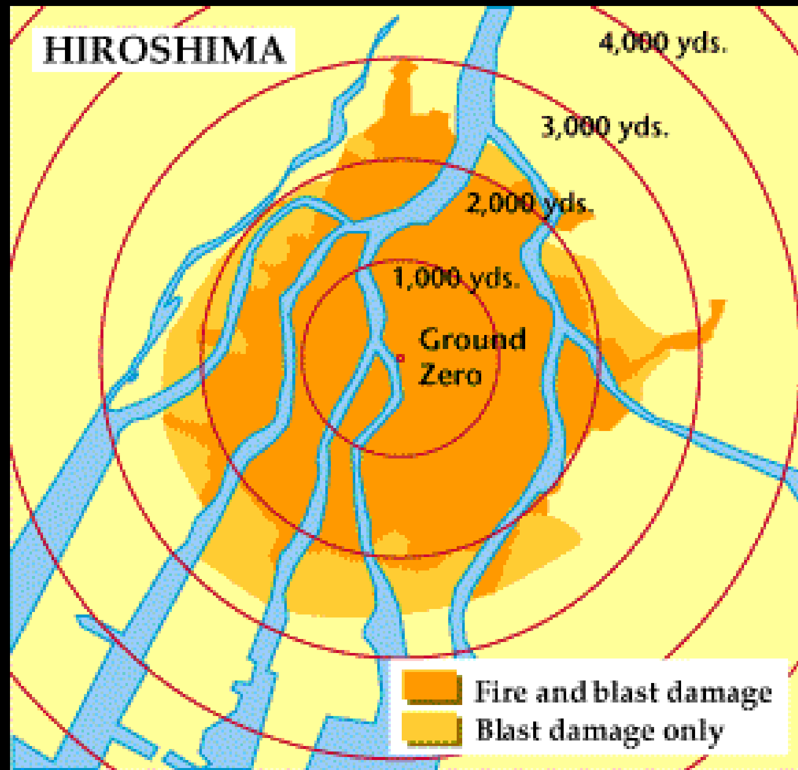
Shock, blast, and firestorm

Building Destruction

The shock wave traveled the first 2.3 miles in 10 seconds.

Wind speed 1000 miles/hour
Shock pressure of 700000 lbs/m^2
Shock temperature ~2000000 ^oC

70,000 immediate deaths
140,000 subsequent deaths



Distance from Ground Zero (km)	Killed	Injured	Population
0 -1.0	86%	10%	31,200
1.0 - 2.5	27%	37%	144,800
2.5 - 5.0	2%	25%	80,300
Total	**27%**	**30%**	**256,300**

Why Nagasaki?

Nagasaki was at the bottom of the pre-identified list of the Target Committee, weather conditions dictated the choice.

The reason for being on the target list was a concern for psychological effect. Nagasaki was added shortly before the first mission as the last on the list of alternate targets. Kyoto was considered to be the first choice because of its history, as the ancient capital, and "the advantage of the people being more highly intelligent and hence better able to appreciate the significance of the weapon.“

These factors were present in Nagasaki as well. The city had been an ancient center of trade with foreign countries, first with China, Vietnam and south Asia. Later when trade with the outside world was cut off, Nagasaki remained a Portuguese outpost. Nagasaki was a religious center for Catholicism as well as Buddhism. As a result literacy was high. In addition it held vital war related industry, being the home of the Mitsubishi Aircraft plant and the Ohashi Arms factory.

Why drop a second bomb?

Why drop the second bomb at all? Hiroshima has been justified as a way to save the lives that an invasion of Japan would cause. It has been explained as a way to impress the Russians and ensure American superiority in Asia.

By August 1945 the Japanese were all but defeated. The Soviet declaration of war was scheduled for August 15. Truman wrote in his diary about this event, **"When this happens, Fini Japs."**

On August 9, 1945 the Japanese were reeling from the effects of the bomb on Hiroshima. Their surrender was inevitable before the 15th.
Why drop a second bomb?

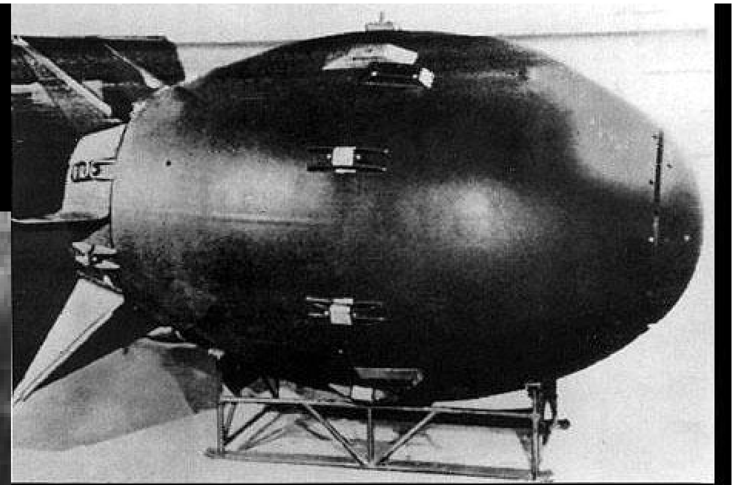
Is it revenge for Pearl Harbor or is the only reason that:

the Americans had two bombs?

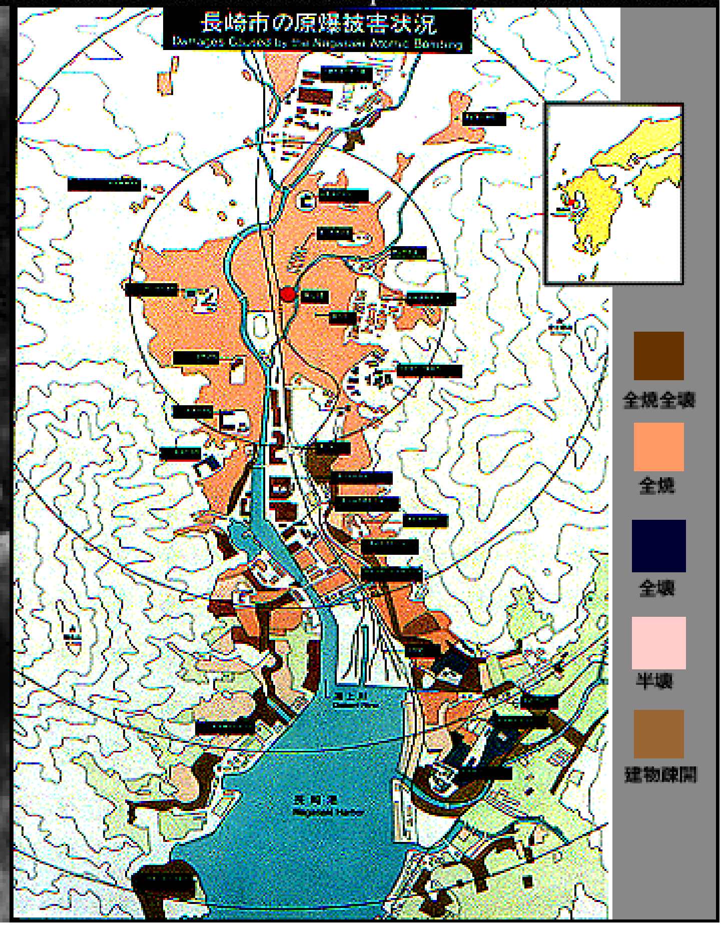
“When you have to deal with a beast you have to treat him as a beast."
–President Harry S. Truman, August 1945

"Now is the time to exterminate the Yellow Peril for all time… Let the rats squeal."
—Congressman Charles A. Plumley, August 1945

Nagasaki



The "Fatman" atomic bomb used plutonium as its fissionable core



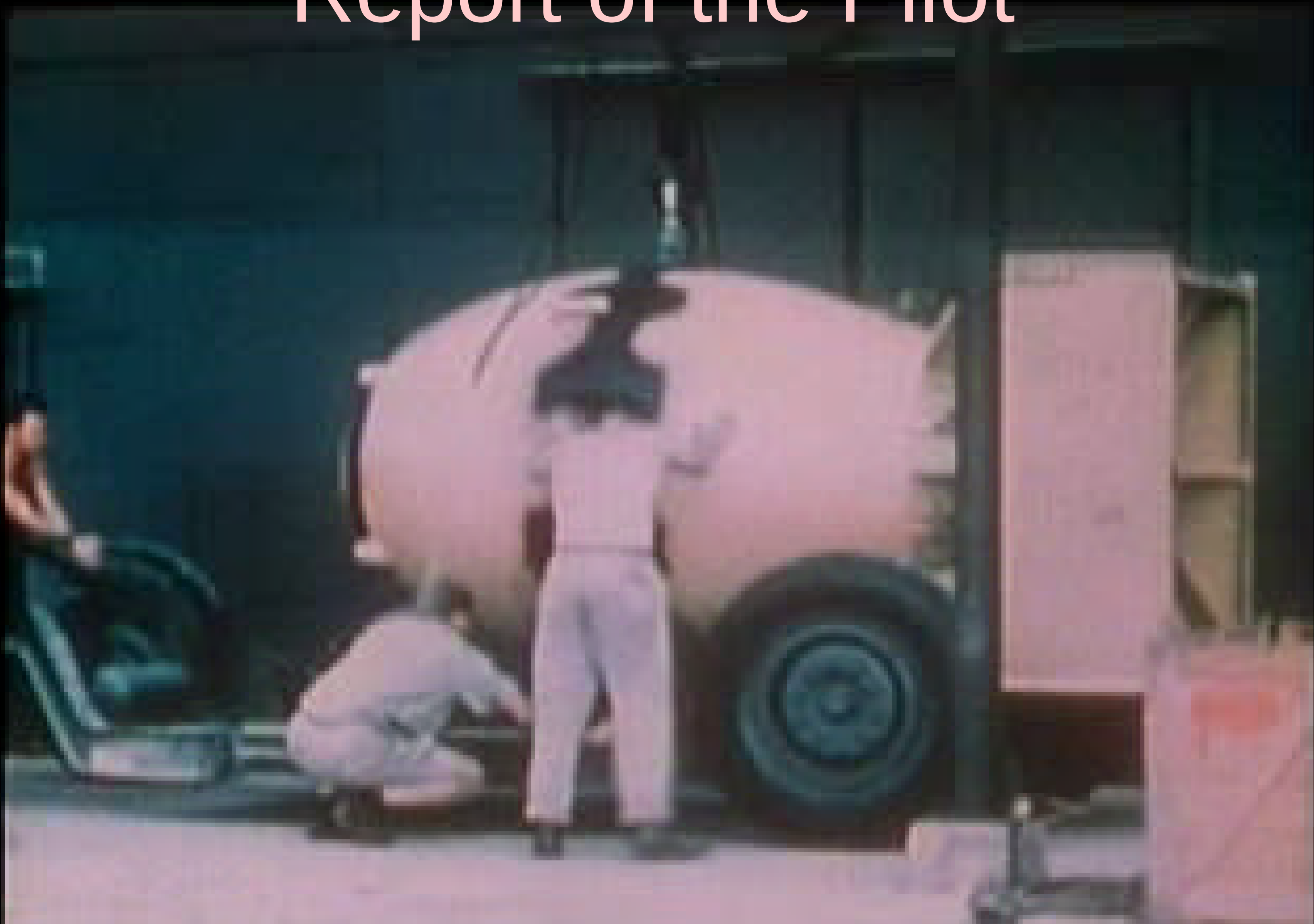
Surveying the results

Nagasaki before the blast

Nagasaki after the atomic blast

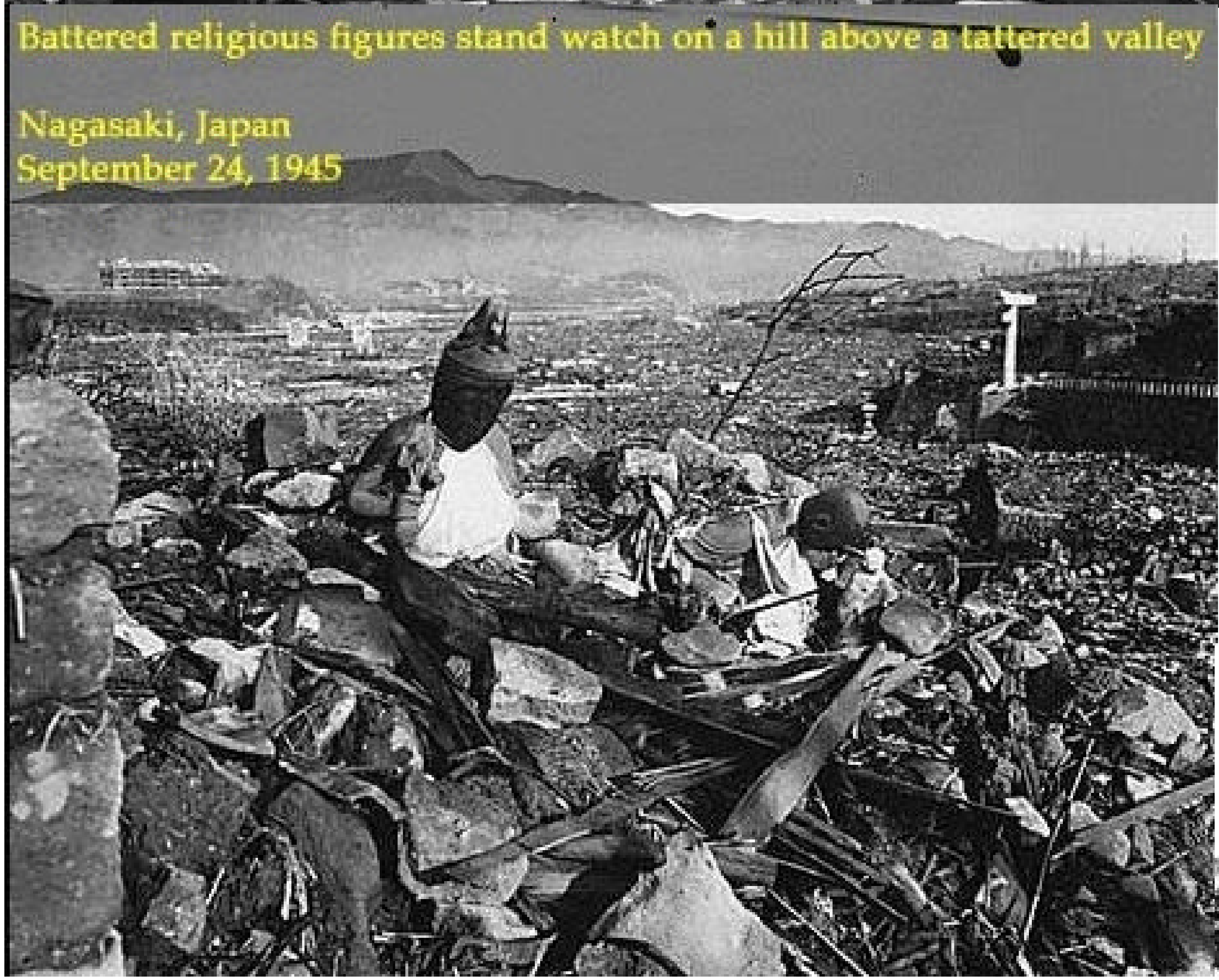
On August 9, 1945 at 9:44 a.m. “Bockscar”, a B-29 carrying Fat Man, the world's third atomic bomb, arrives at its primary target, Kokura. The city is covered in haze and smoke from an American bombing raid on a nearby city. Bockscar turns to its secondary target Nagasaki. At 11:02 a.m. the world's third atomic bomb explosion devastates Nagasaki, the intense heat and blast indiscriminately slaughters its Inhabitants, 74,000 people died immediately. 10,000 Catholics died since target was suburb Urakami, a center of Japanese Catholicism.

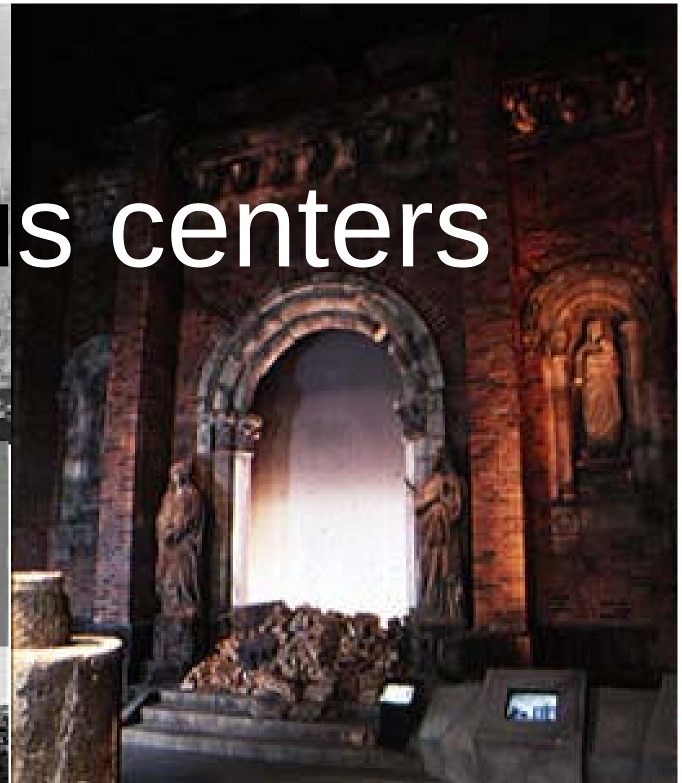
Report of the Pilot



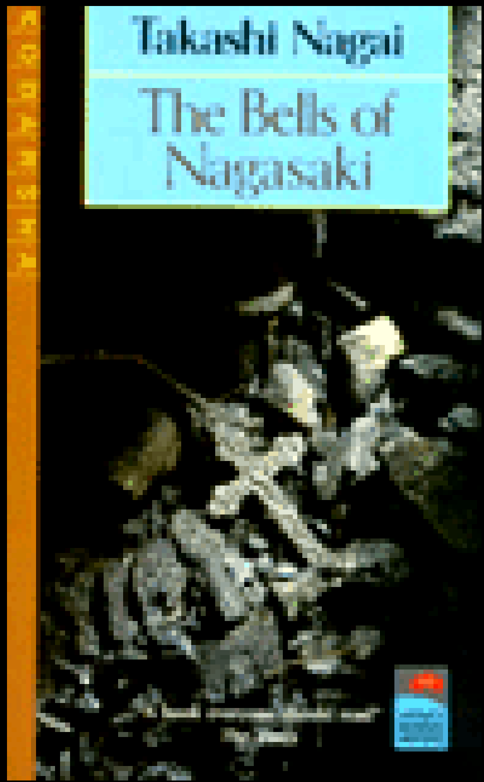

The effects
of the blast
© SHOGO

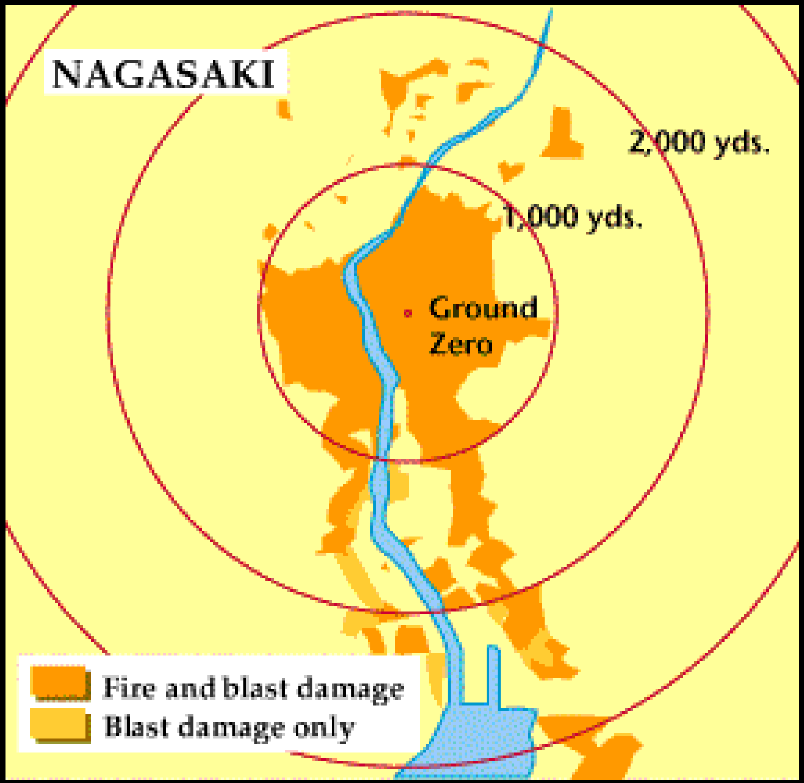
Cultural and religious centers





Urakami Cathedral was the largest church in the entire Orient. The Urakami parish counted 14,000 members.

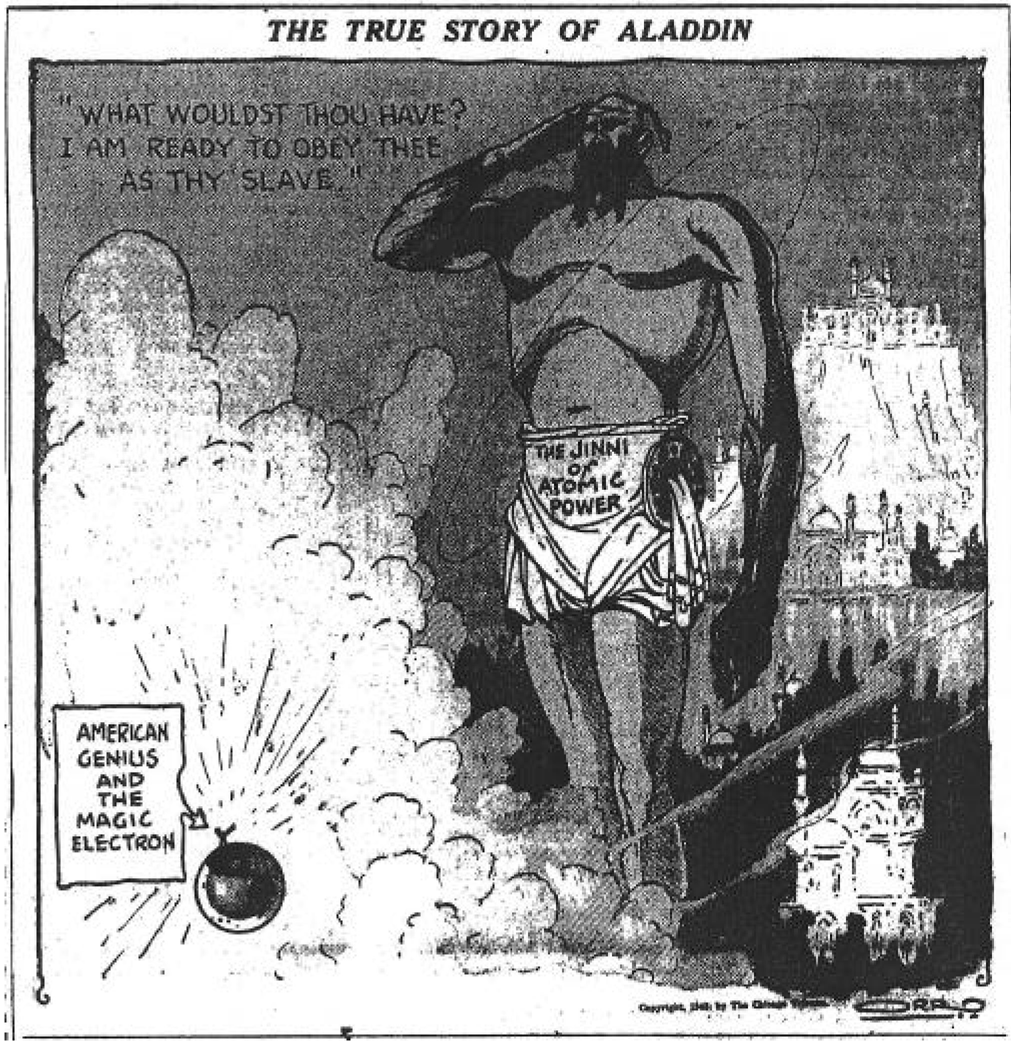


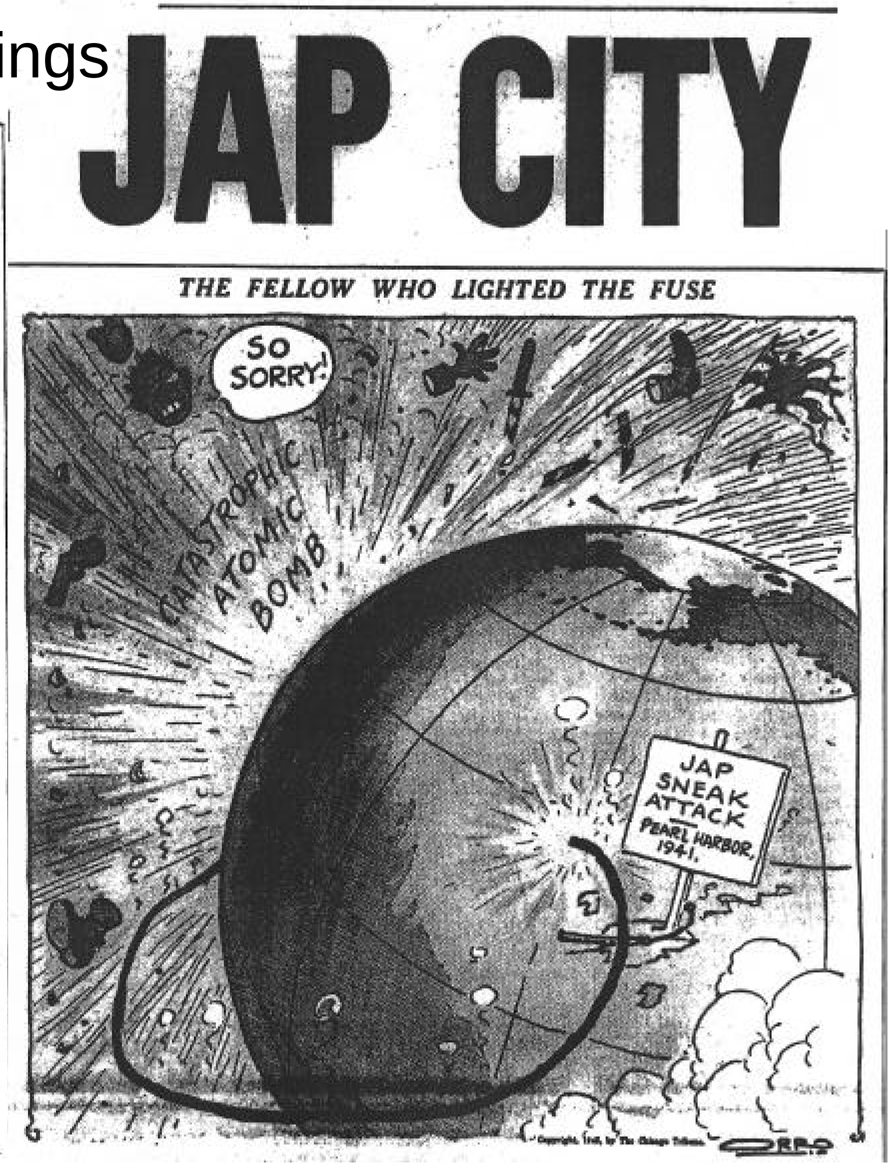


Distance from Ground Zero (km)	Killed	Injured	Population
0 - 1.0	88%	6%	30,900
1.0 - 2.5	34%	29%	144,800
2.5 - 5.0	11%	10%	115,200
Total	**22%**	**12%**	**173,800**

Th

Between triumph and revenge feelings





Japan’s Unconditional Surrender

September 2, 1945

On board of battleship Missouri in Tokyo Bay

Gen. MacArthur referred to the nuclear bomb attacks on Hiroshima and Nagasaki, saying they had "revised the traditional concept of war".

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Moral Opposition

Moral doubts of single participants:

- Joseph Rotblat (1908-2005)
- Leo Szilard (1898-1964)
- Albert Einstein (1879-1955)
- J. Robert Oppenheimer (1904-1967)

Joseph Rotblat

- Polish emigrant to Great Britain,
- Close collaborator of Chadwick
- Initiator and participant at the British (tube alloy) bomb project .
- He moved to Los Alamos to join the Manhattan Project

Rotblat resigned after defeat of Germany in objection to project continuation
US Government accused him to be a spy,
US press later called him an “unknown” physicist of no importance
Rotblat moved back to the United Kingdom

'I didn't know anything until I heard the BBC announcement on August 6. It came as a terrible shock. My idea had been to make the bomb to prevent it being used, and here it had been used immediately after it was made, and against civilian populations.'

Organization of Protest

Rotblat became one of the most prominent critics of the nuclear arms race, signing the Russell Einstein Manifesto in 1955, and with Bertrand Russell he founded the Pugwash Conference in 1957. Despite the Iron Curtain and the Cold War, he advocated establishing links between scientists from the West and East. Just as the Hippocratic Oath provides a code of conduct for physicians, he thought that scientists should have their own code of moral conduct. He was knighted in 1998 and died in 2005.

The moral conflict of science

"We scientists, whose tragic destiny it has been to help to make the methods of annihilation ever more gruesome and more effective, must consider it our solemn and transcendent duty to do all in our power in preventing these weapons from being used....

What task could possibly be more important to us?"

The Case of J.R. Oppenheimer

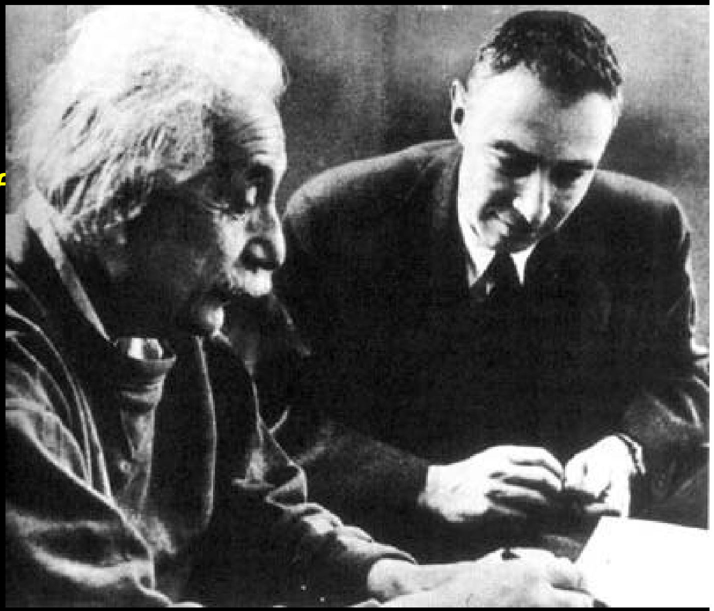
We knew the world would not be the same. A few people laughed, a few people cried, most people were silent. I remembered the line from the Hindu scripture, the Bhagavad-Gita. Vishnu is trying to persuade the Prince that he should do his duty and to impress him takes on his multi-armed form and says,

"Now, I am become Death, the destroyer of worlds."

I suppose we all thought that one way or another.

- J. Robert Oppenheimer

A wave of remorse seems to have hit Oppenheimer shortly after Nagasaki was destroyed by the second atomic bomb, a blow criticized by many of the bomb builders as gratuitous and unnecessary. Within weeks his strut was gone. Abruptly, he resigned his position, packed up, and departed Los Alamos. In a somber farewell speech in October he said that pride in building the bomb must be tempered with a profound concern. *“If atomic bombs are to be added as new weapons to the arsenals of a warring world ...then the time will come when mankind will curse the names of Los Alamos and Hiroshima”.* Nine days later Oppenheimer was brought to see President Truman by Secretary of War Robert Patterson. "Mr. President," he said, *"I feel I have blood on my hands."* Truman was disgusted, described Oppenheimer later as a "cry-baby scientist," and told Dean Acheson, "I don't want to see that son-of-a-bitch in this office ever again." That was the last time Oppenheimer spoke so baldly of guilt, but he did not shed it. Three years later, in February 1948, *Time* magazine quoted him as saying, *"In some sort of crude sense which no vulgarity, no humor, no overstatement can quite extinguish, the physicists have known sin; and this is a knowledge which they cannot lose."*



1947-1966, Princeton, Institute of Advanced Studies

Acheson-Lilienthal Report

Dean Acheson was charged to design a plan of international control on nuclear weapon development. Acheson was well aware of his limited understanding of the scientific aspects of atomic energy. To assist the committee, he appointed a board of consultants that would work out the details of the proposal. Its chairman was David Lilienthal, an energetic, optimistic man who had successfully headed one of the most admired achievements of the New Deal, the Tennessee Valley Authority. By far the most influential consultant was J. Robert Oppenheimer, the nuclear physicist who had been the director of the Los Alamos laboratory during the war and was now at the University of California at Berkeley. On March 17, 1946, the Acheson-Lilienthal report was ready. The key was an Atomic Development Authority that would control the whole field of atomic energy, from mining through manufacturing. Rather than rely on international inspection teams -- what might be called atomic cops -- the consultants proposed to control potential cheating at the source, the uranium and thorium mines. This solution, developed by Oppenheimer, Acheson termed "brilliant and profound." The Acheson-Lilienthal report recognized that with the fundamentals of atomic energy widely known, it was impossible to outlaw atomic weapons. It concluded that "so long as intrinsically dangerous activities may be carried out by nations, rivalries are inevitable" and that, therefore, a single international authority should become the only legal participant in activities associated with atomic arms.

The Baruch Plan

Bernard Baruch a conservative Wall Street Banker was charged by Truman to present the plan to the newly founded United Nations. Baruch made it clear he was not about to accept the report as written and present it to the United Nations; as he put it, he would not be "a messenger boy." Moreover, he would not include any scientists among his advisers. Baruch assured Lilienthal that he could "smell his way through." Baruch was worried about putting profitable US mining business under international control.

Baruch made two key changes in the Acheson-Lilienthal report that proved fatal. He insisted that swift and sure penalties greet violations and that punishment not be subject to a Security Council veto. Such conditions, Acheson believed, were a prescription for failure.

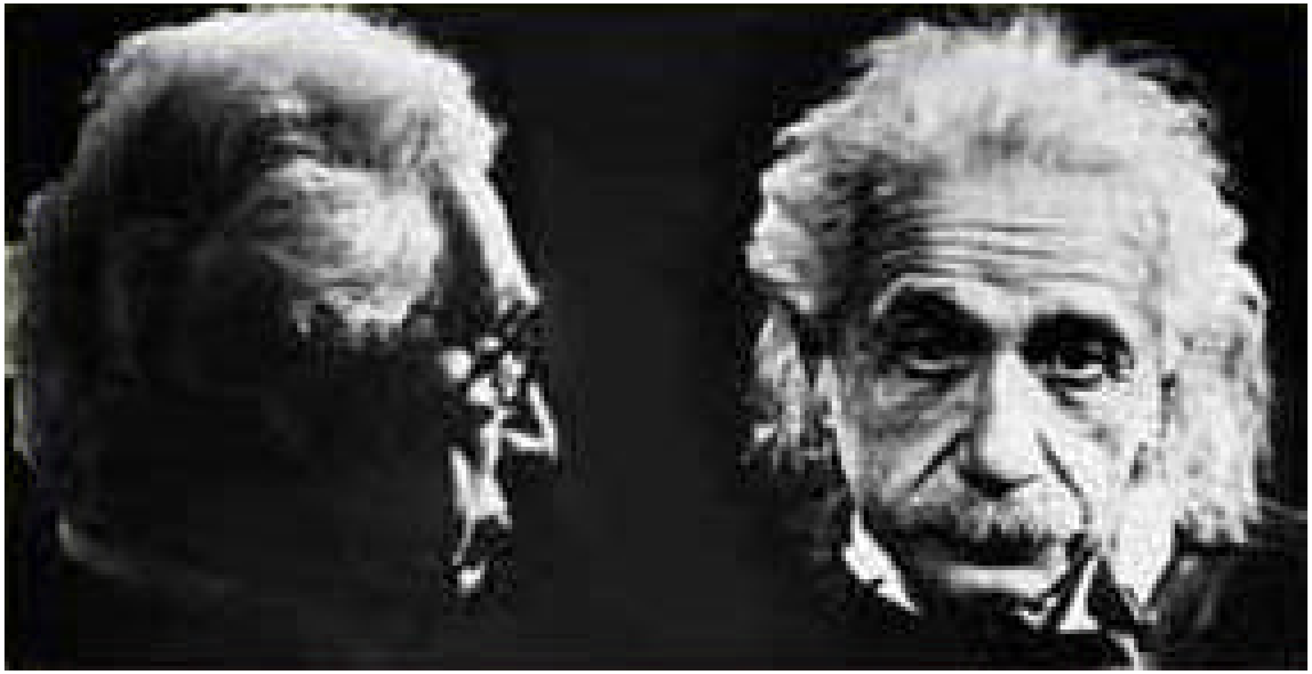
Failure of the Baruch Plan

The Soviet Union, a non-nuclear power, insisted upon retaining its United Nations veto and argued that the abolition of atomic weapons should precede the establishment of an international authority. Negotiations could not proceed fairly, the Russians maintained, as long as the United States could use its atomic monopoly to coerce other nations into accepting its plan.

Andrei Gromyko, the Soviet delegate, proposed an international convention prohibiting the possession, production, and use of nuclear weapons. Only after the convention was implemented, should measures be considered to ensure “the strict observance of the terms and obligations.”

The Russell Einstein Manifesto

London July 9 1955



Bertrand Russell and Albert Einstein were two of the leading intellectual figures of the 20th century. Russell was a philosopher, mathematician and Nobel Laureate in Literature. Einstein was a theoretical physicist, considered the greatest scientist of his time, and a Nobel Laureate in Physics.

IN the tragic situation which confronts humanity, we feel that scientists should assemble in conference to appraise the perils that have arisen as a result of the development of weapons of mass destruction, and to discuss a resolution in the spirit of the appended draft.

Russell Einstein Manifesto

"In view of the fact that in any future world war nuclear weapons will certainly be employed, and that such weapons threaten the continued existence of mankind, we urge the governments of the world to realize, and to acknowledge publicly, that their purpose cannot be furthered by a world war, and we urge them, consequently, to find peaceful means for the settlement of all matters of dispute between them."

11 Signatures

Max Born (1954)
Percy W. Bridgman (1946)
Albert Einstein (1921)
Leopold Infeld
Frederic Joliot-Curie (1935)
Herman J. Muller (1946)
Linus Pauling (1954,1962)
Cecil F. Powell (1950)
Joseph Rotblat (1995)
Bertrand Russell (1950)
Hideki Yukawa (1949)

The Russell-Einstein Manifesto makes the following points:

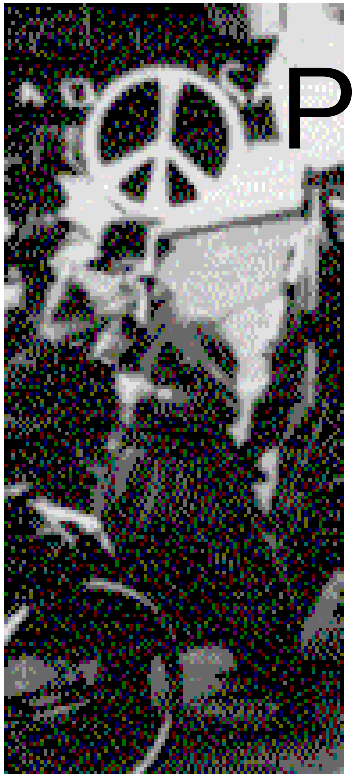
- Scientists have special responsibilities to awaken the public to the technological threats, particularly nuclear threats, confronting humanity.
- Those scientists with the greatest knowledge of the situation appear to be the most concerned.
- Nuclear weapons endanger our largest cities and threaten the future of humanity.
- In the circumstance of prevailing nuclear threat, humankind must put aside its differences and confront this overriding problem.
- The prohibition of modern weapons is not a sufficient solution to the threat; war as an institution must be abolished.
- Nonetheless, as a first step the nuclear weapons states should renounce these weapons.
- The choice before humanity is to find peaceful means of settling conflicts or to face "universal death."

The Pugwash Conference

Russell and Rotblat proposed an annual international conference on nuclear disarmament. The first conference was planned by Nehru for India, but this was postponed due to the outbreak of the Suez crisis. An offer by Aristotle Onassis to finance a meeting at Monaco was rejected. Cyrus Eaton, an industrialist in America, intervened. Eaton had been a trustee of the University of Chicago and had known Russell (a visiting professor there) in 1938. He provided financial support for the conference of scientists to meet in his hometown of Pugwash, Nova Scotia. The first Pugwash Conference on Science and World Affairs was held in 1957.

The Nobel Peace Prize 1995 for Joseph Rotblat and Pugwash Movement
"for their efforts to diminish the part played by nuclear arms in international politics and, in the longer run, to eliminate such arms"

http://www.pugwash.org/



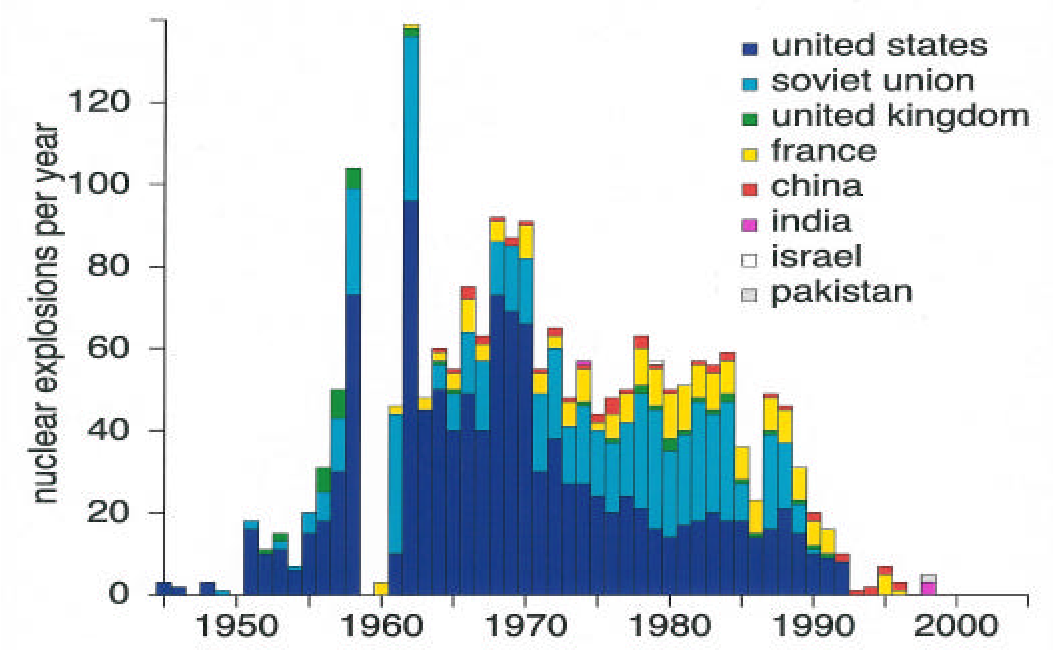
Protest Movements

Annual Easter March
in Western Europe against US and Soviet armament

Anti Nuclear Rallies from ~1958 -1989

Cold War and Proliferation

After Trinity, Hiroshima, and Nagasaki and the defeat of Germany, the US believed to be in the absolute lead in nuclear weapon technology, US even supported Baruch plan for a short period of six months. But proliferation had

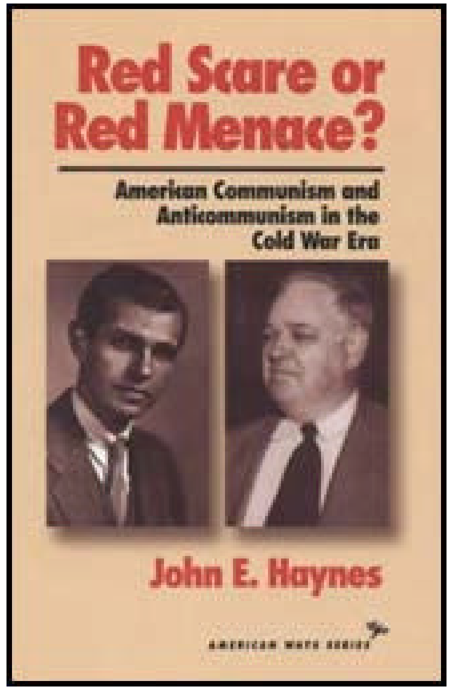


started even before the Trinity test and developed rapidly to a whole set of Nuclear Powers over the following decades

Spies and Proliferation

At Potsdam conference 1945 Stalin was informed about US bomb project. Efficient Russian spy system in US had been established based on US communist cells and emigrant sympathies and worries about single dominant political and military power.

Klaus Fuchs, German born British physicist, part of the British Collaboration at the Manhattan project passed information about Manhattan project and bomb development and design Plans to Russia. Arrested in 1949 in Britain and convicted to 14 years of prison. He served 9 years - returned to East Germany as Director of the Rossendorf Nuclear Research center.



Fuchs case caused panic and enhanced security in US. Fear of communist take-over was fired by McCarthy propaganda. Numerous subsequent arrests and trials culminating in Rosenberg case!

The Spy Story

PART I

Los Angeles Times

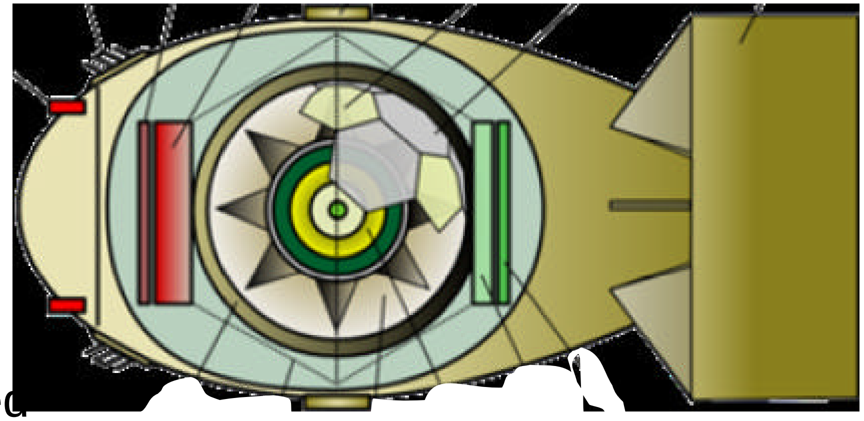
TRUMAN SAYS RUSS HAVE A-BOM

City Heat Hits 102-Deg. Mark as Desert Air Moves to Coast

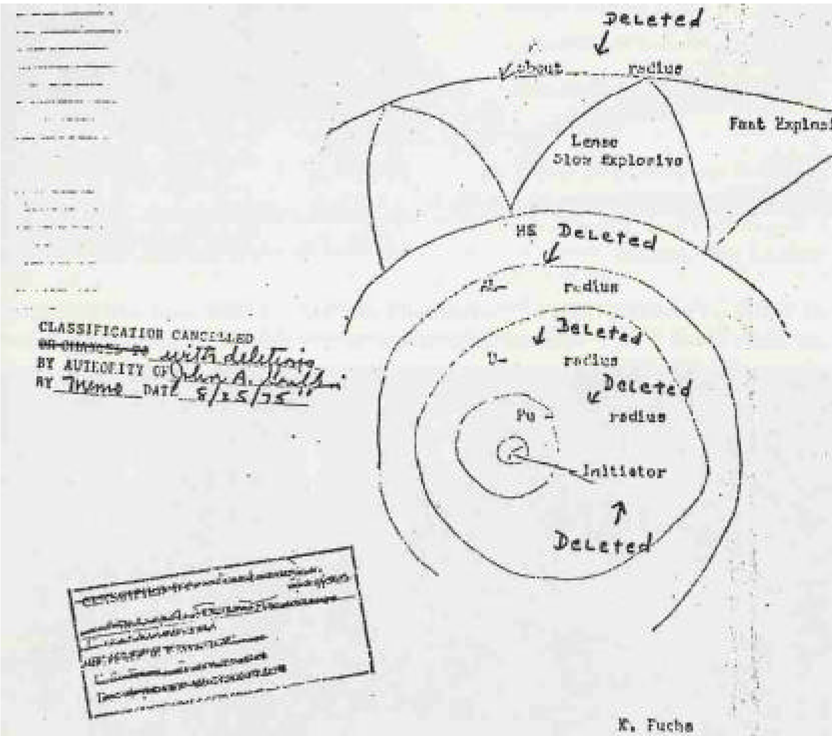
LAWMAKER SAYS STOLEN U.S. SECRETS AIDED RUSS

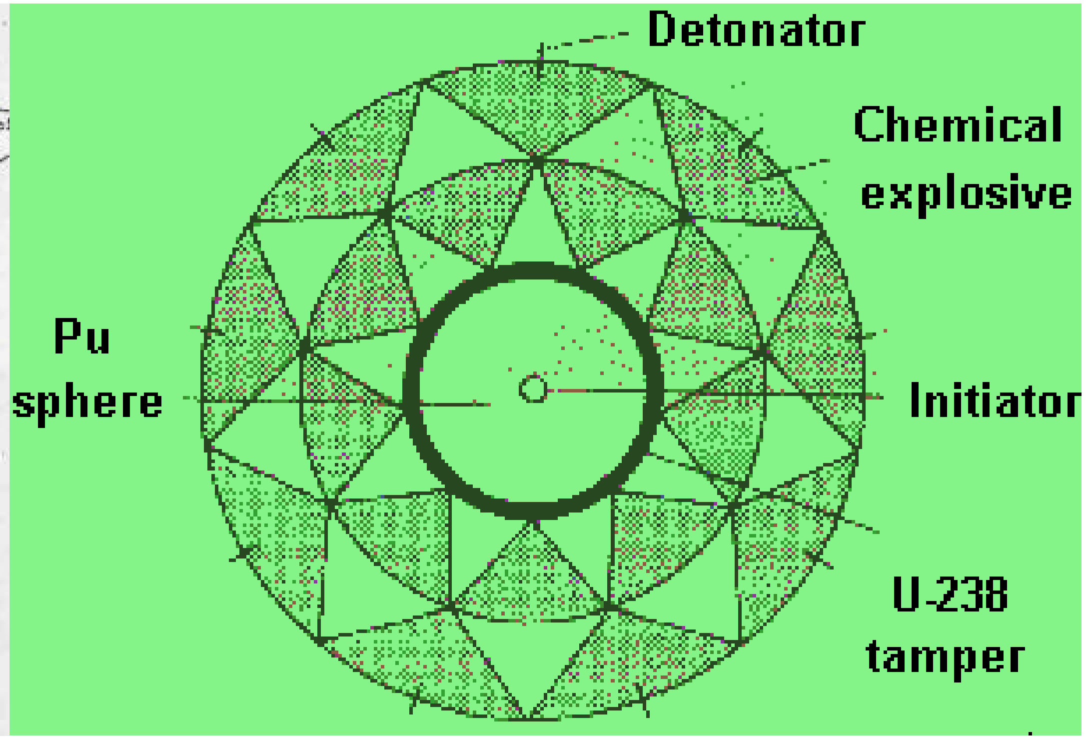
STALIN WITNESSED TESTING OF A-BOMB

Fat Man Design



Copied by Klaus Fuchs and forwarded to Russian courier person (Harry Gold).





Spy Scare

Value of Spy Work,
Information on trends not detail of design

It is unknown whether Fuchs' fission information had a substantial impact. Considering that the pace of the Soviet program was set primarily by the amount of uranium they could procure, it is hard for scholars to accurately judge how much "time" this saved the Soviets. Some former Soviet scientists said they were actually hampered by Fuchs' data, because Beria insisted that their first bomb (“Joe-1") should resemble the American plutonium bomb (“Fat Man") as much as possible, even though the scientists had discovered a number of improvements and different designs.

The information Fuchs passed on the hydrogen bomb was too early to be of much material use: the key methods of making a hydrogen bomb work had not yet been discovered in the United States during the time Fuchs was working on the project (the Ulam Teller mechanism was not proposed until 1951). Soviet physicists would later note that they could see as well as the Americans could that the early designs by Fuchs and Teller were useless.

Soviet Nuclear Physics

Outstanding and leading Soviet discoveries and scientists:

1934 first European cyclotron at the Radium Institute in Leningrad
1938 discussion of chain reactions for energy production
1940 Georgy Flerov (1913-1990) discovered spontaneous fission
1940 “underground” experiments in Moscow Metro for Cosmic Ray reduction
1940 Yakov Zeldovich (1914-1987) predicted chain reaction & ^{235}U fission bomb
1940 Formation of Uranium Commission to identify Soviet Uranium mines
1940 Yakov Zeldovich & Yuly Khariton predicted critical mass for ^{235}U as 10kg.
1942 Flerow submitted first Uranium Bomb design to Kurchatov

Initially Soviet Bomb program was driven by competition with presumed British bomb program, the “Tube Alloys project” (triggered by the Frisch prediction of 1kg critical mass). The “Tube Alloys project” subsequently merged with the Manhattan Project in 1943. Information came from British spy circles.

Main handicap of Soviet Program was lack of Uranium until 1949.

Start of Soviet Weapons Program

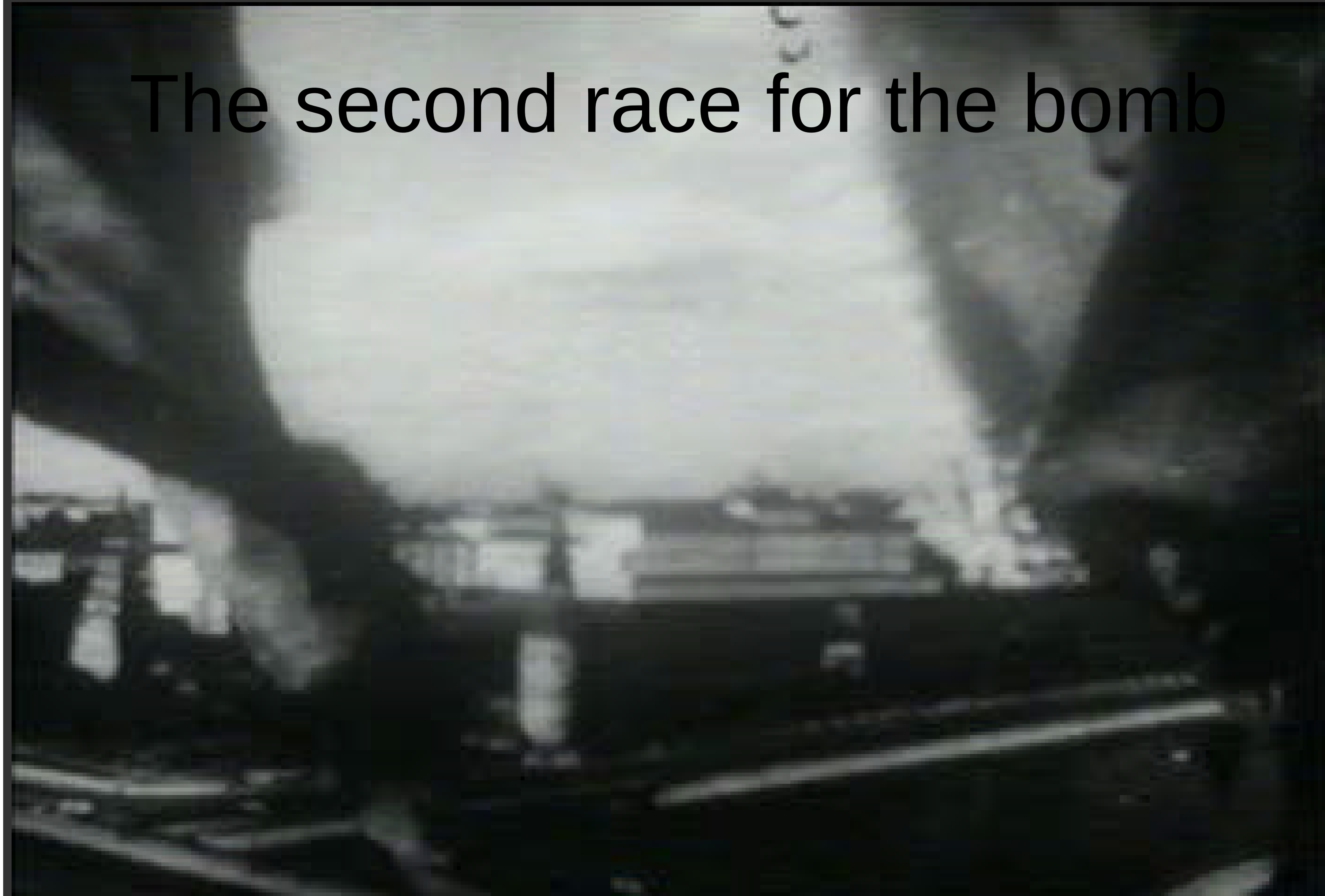
Program was ordered by Stalin in 1943 after being informed about US efforts. The administrative head of the program was Lavrenti Beria.

Scientific director was Igor Kurchatov, Who headed the Russian nuclear research program and built the first Russian cyclotron in 1934.

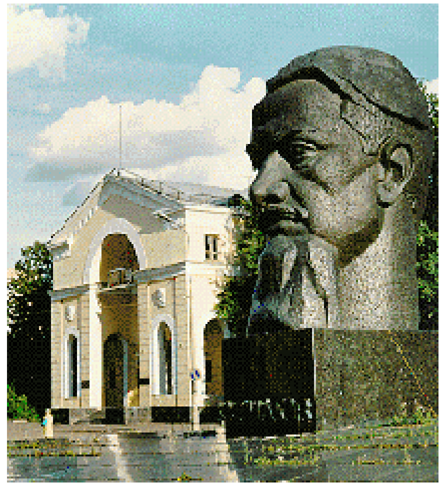
Program was initially limited, ~100 people, 25 physicists

Lavrenty Pavlovich Beria (1899-1953), Soviet politician and police chief, is remembered chiefly as the executor of Stalin's Great Purge of the 1930s His period of greatest power was during and after WW-II. After Stalin's death he was removed from office and executed by Stalin's successors.

The second race for the bomb



Citizen Kurchatov



(1903-1960); head of the Soviet Nuclear physics program. He developed the big Russian Cyclotron 1934, built the first Russian reactor 1946, developed the first Russian fission Bomb 1949, and the first fusion bomb 1955. Named after him are the Kurchatov Institute and element 104 Kurchatovium.

Kurchatov managed to build with full support of Stalin and Beria a competitive nuclear research program from 1943 to 1945, stimulated by successful Trinity test. He built entire weapons research laboratory structure called Arzamas-16, taking Manhattan project structure as a guide. Arzamas-16 was often referred to as Los Arzamas (since 1993 sister city of Los Alamos). Arzamas-16 represented a network of “secret cities” and research labs.

Sarov Monastery

THE OLD SAROV MONASTERY is seen in this reproduction of an old print (courtesy of German Goncharov). Sarov is where the Soviet "Los Alamos" was built, the closed city known variously as Arzamas-16, KB-11 and Kremlev. Today, once again, the city is called Sarov.

In1946 little monastery town Sarov disappeared from Russian official maps. The town became the site for the first Russian nuclear weapons laboratory

Arzamas-16

Presently home of two weapons facilities:
The VNIEF nuclear weapon design institute
AVANGARD warhead assembly facility

Secret Cities

Arzamas-16: 29 km^2 about 82,000 population, fenced off from surrounding area. Has been center for Soviet and Russian nuclear research for 50 years. Besides Arzamas-16 there existed nearly 50 additional nuclear weapon research, production and test sites distributed over area of former Soviet Union. Privileged workers and researchers under heavy KGB surveillance. The camps and facilities were all build by GULAG workers and POWs.

GULAG work force

~116 GULAG camps, ~18 camps for nuclear bomb related projects (mines)
~3,000,000 prisoners, ~60,000 inmates working on nuclear bomb related projects
~3,400,000 German POWs, last 10,000 released in1955 (~2,000,000 missing)

~ 1500 cal/day: 600 grams of black bread every day, spaghetti, a little meat, sugar, vegetables, and rice.

Nuclear Facilities in Russia today

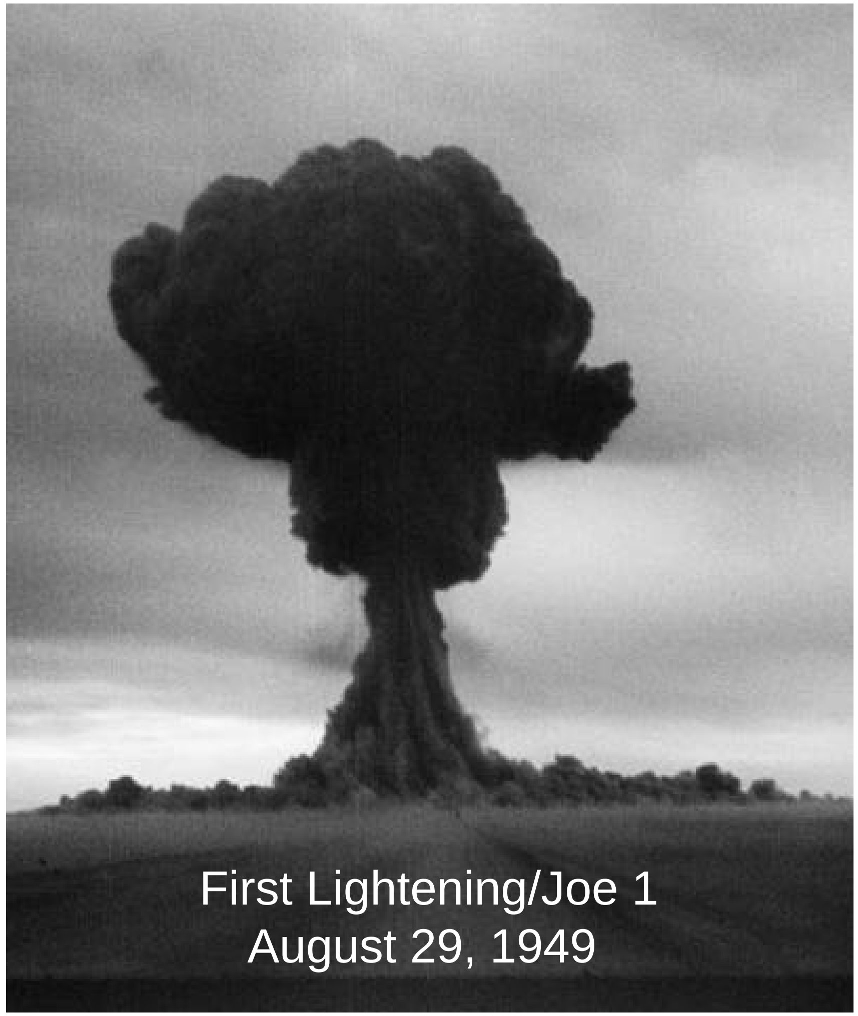
Success

Yuli Khariton (1904-1996)

Leading Russian weapon designer,
last living pupil of Rutherford

Plutonium based 22KT bomb; the plutonium was generated at Cheliabinsk-40 breeder reactor built by Kurchatov in 1947

The Soviet first bomb was called by the Americans "Joe 1", Joe-1 was an exact copy of “fat man” based on Intelligence from Klaus Fuchs and other US-based scientists. The copy approach was made on insistence of Beria to warrant quick success. The explosion at the Semipalatinsk test site in Kazakhstan was successful.

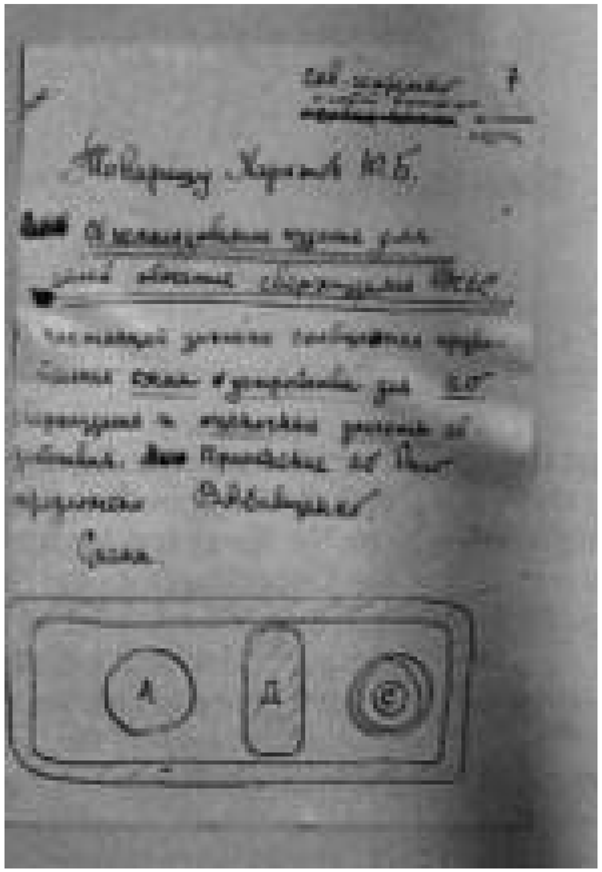


First Lightening/Joe 1
August 29, 1949

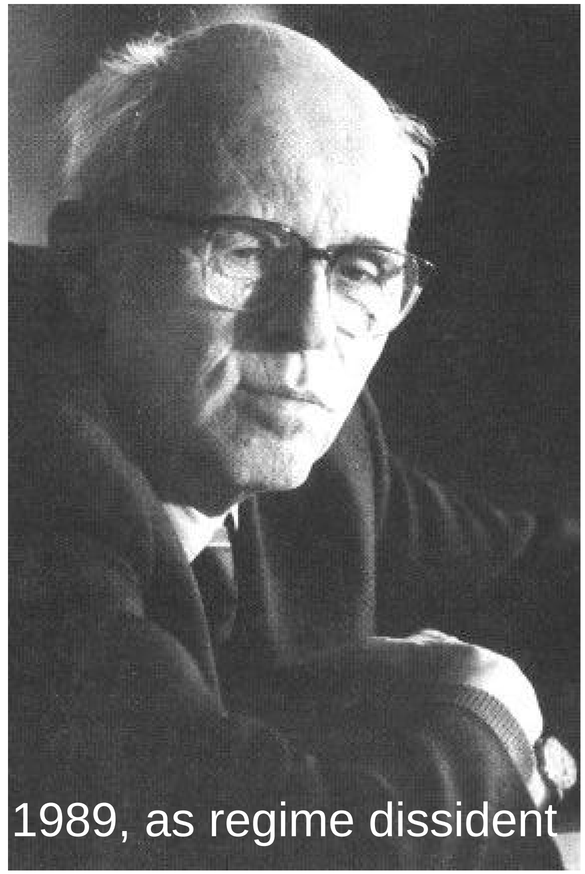
New Sloyka design by Sakharov

Layer Cake: alternate layers of light (liquid deuterium and tritium) & heavy (^{235}U) nuclear fuel to trigger a fission fusion reaction.

In 1950
As “father” of the Soviet
Hydrogen Bomb

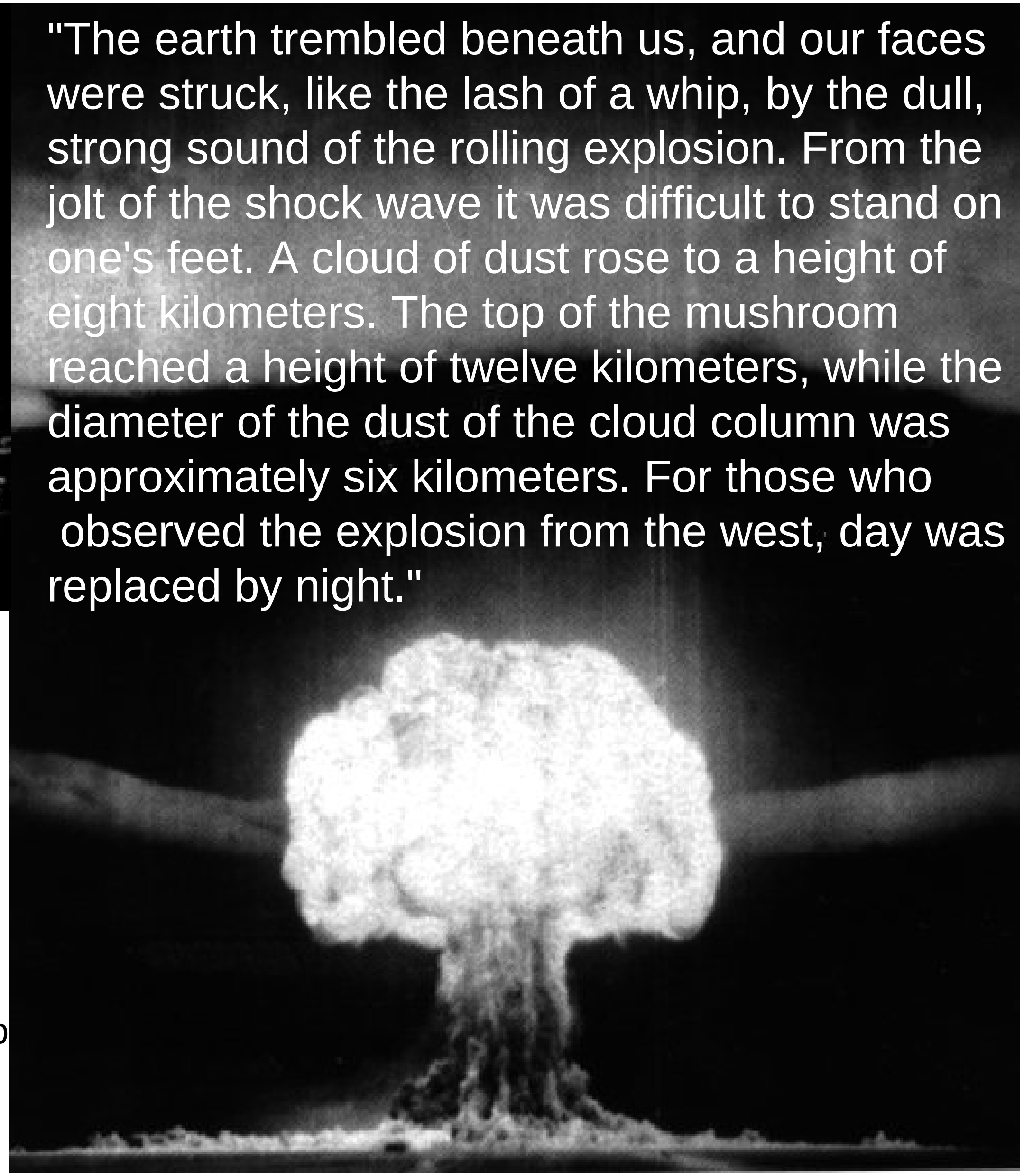


First design study
by Andrei Sakharov



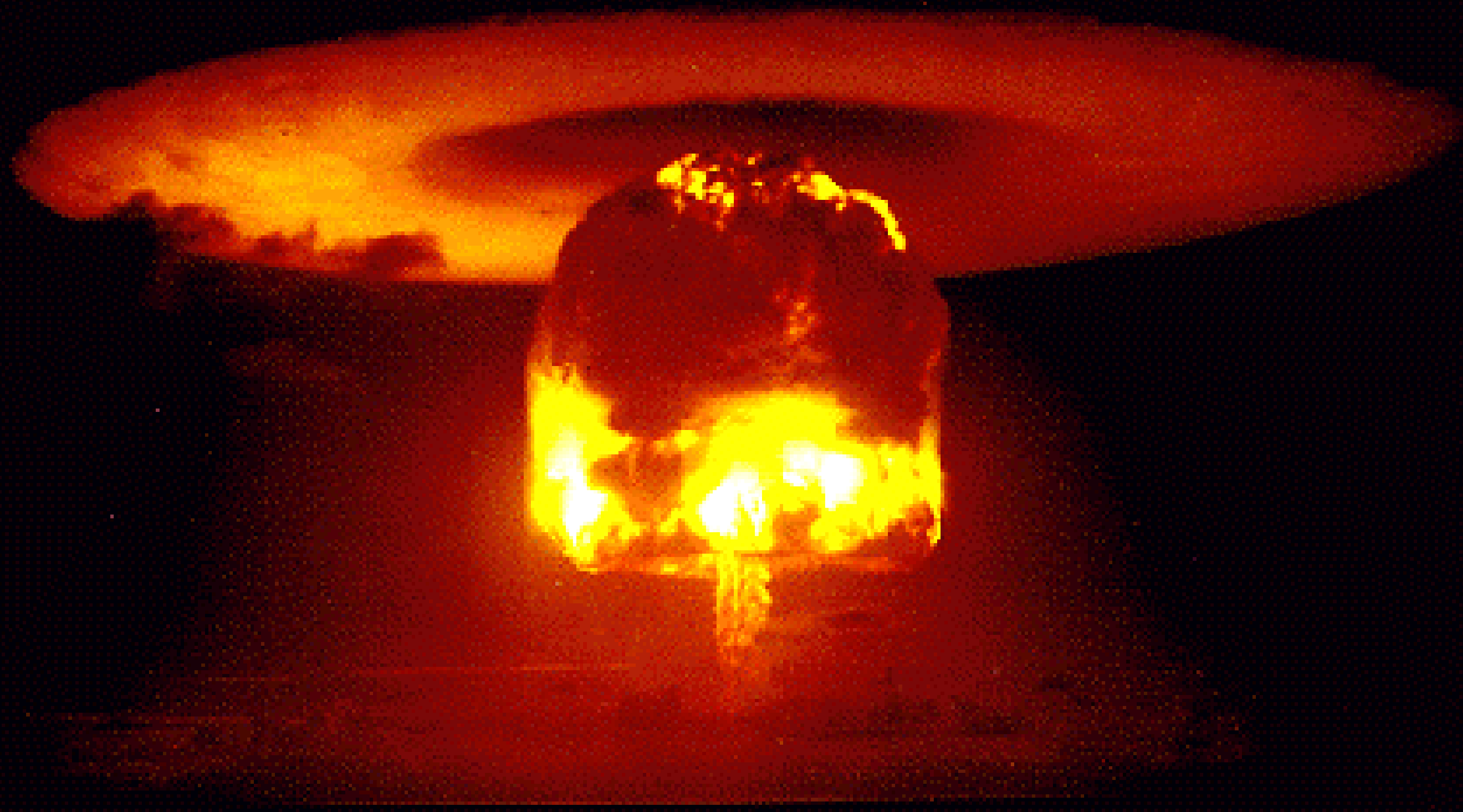
1989, as regime dissident

Sloyka-design, RDS-6 or Joe-4

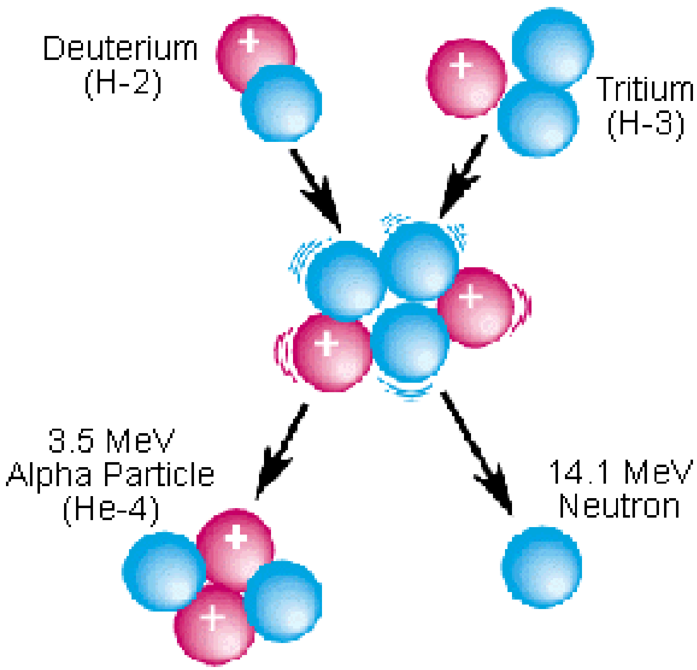


The RDS-6s used a ^{235}U fissile core surrounded by alternating layers of fusion fuel (^{6}Li deuteride with tritium), and fusion tamper (natural uranium) inside a high explosive implosion system. The small ^{235}U fission bomb acted as the trigger (about 40 kt). The total yield was 400 Kt, and 15-20% of the energy was released by fusion, and 90% due to the fission reaction.

The Hydrogen Bomb



The fusion process



Deuterium-Tritium Fusion Reaction

$^{2}H+^{3}H \Rightarrow ^{4}He+n+Q \equiv 17.6$ MeV

Energy release Q=17.6 MeV

In comparison

$^{2}H+^{2}H \Rightarrow ^{1}H+^{3}H +Q \equiv 4.0$ MeV

$^{2}H+^{2}H \Rightarrow ^{3}He+n +Q \equiv 3.2$ MeV

$^{3}H+^{3}H \Rightarrow ^{4}He+2n+Q \equiv 11.3$ MeV

$^{235}U+n \Rightarrow X_A+X_B+3n +Q \approx 200$ MeV

Fusionable Material, deuterium ^{2}H (D) and tritium ^{3}H (t):

Deuterium: natural occurrence (heavy water) (0.015%).

Tritium: natural occurrence in atmosphere through cosmic ray bombardment; radioactive with $T_{1/2}$=12.3 y.

“Advantages” of hydrogen bomb

Fusion of ^{2}H+^{3}H: $$\frac{Q}{A} = \frac{17.6\ MeV}{(3+2)\ amu} = 3.5\ \frac{MeV}{amu}$$

Fission of ^{235}U: $$\frac{Q}{A} = \frac{200\ MeV}{236\ amu} = 0.85\ \frac{MeV}{amu}$$

Fusion is 4 times more powerful than fission and generates 24 times more neutrons!

Neutron production:

$$^2H + {}^3H: \quad \frac{n}{A} = \frac{1}{5} = 0.2$$

$$^{235}U + n: \quad \frac{n}{A} = \frac{2}{236} = 0.0085$$

Fuel Considerations

Successful operation of hydrogen bomb requires light fusionable fuel.

- ❑ deuterium for d+d based bombs
- ❑ tritium & deuterium for d+t based bombs
- ❑ tritium needs to be replaced regularly
- ❑ on-line produced tritium through $^{6}Li(n,t)$

Industrial production facilities are necessary.

Deuterium Fuel Production

Deuterium separation takes place by electrolysis or chemical catalysts based methods with subsequent distillation.

Electrolysis separates water in oxygen and hydrogen. The hydrogen and deuterium mix can then be liquefied and distilled to separate the two species.

Chemistry based methods include distillation of liquid hydrogen and various chemical exchange processes which exploit the differing affinities of deuterium and hydrogen for various compounds. These include the ammonia-hydrogen system, which uses potassium amide as the catalyst, and the hydrogen sulfide-water system (Girdler Sulfide process). Process enriches to ~15% deuterium.

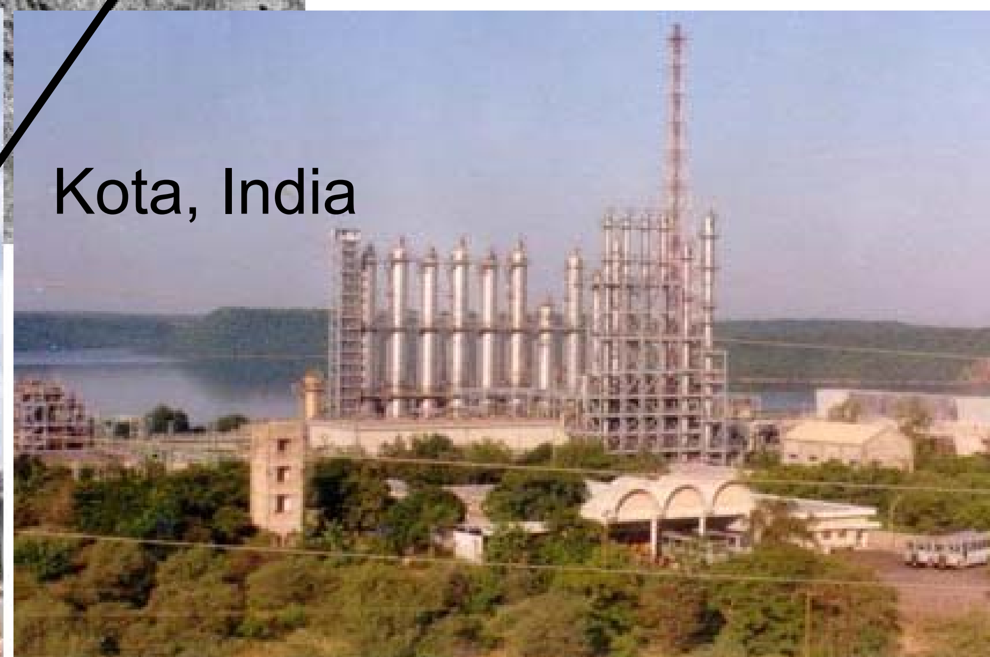
Distillation process of deuterium enriched water leads to 99% enrichment – boiling points of heavy water (101.4 °C) and normal water (100 °C).

Known producers are Argentina, Canada, India, Norway, plus all five declared Nuclear Powers. Recent newcomers are Pakistan and Iran.

Heavy Water Plants

Newly-Identified
Heavy Water Plant
Khushab, Pakistan

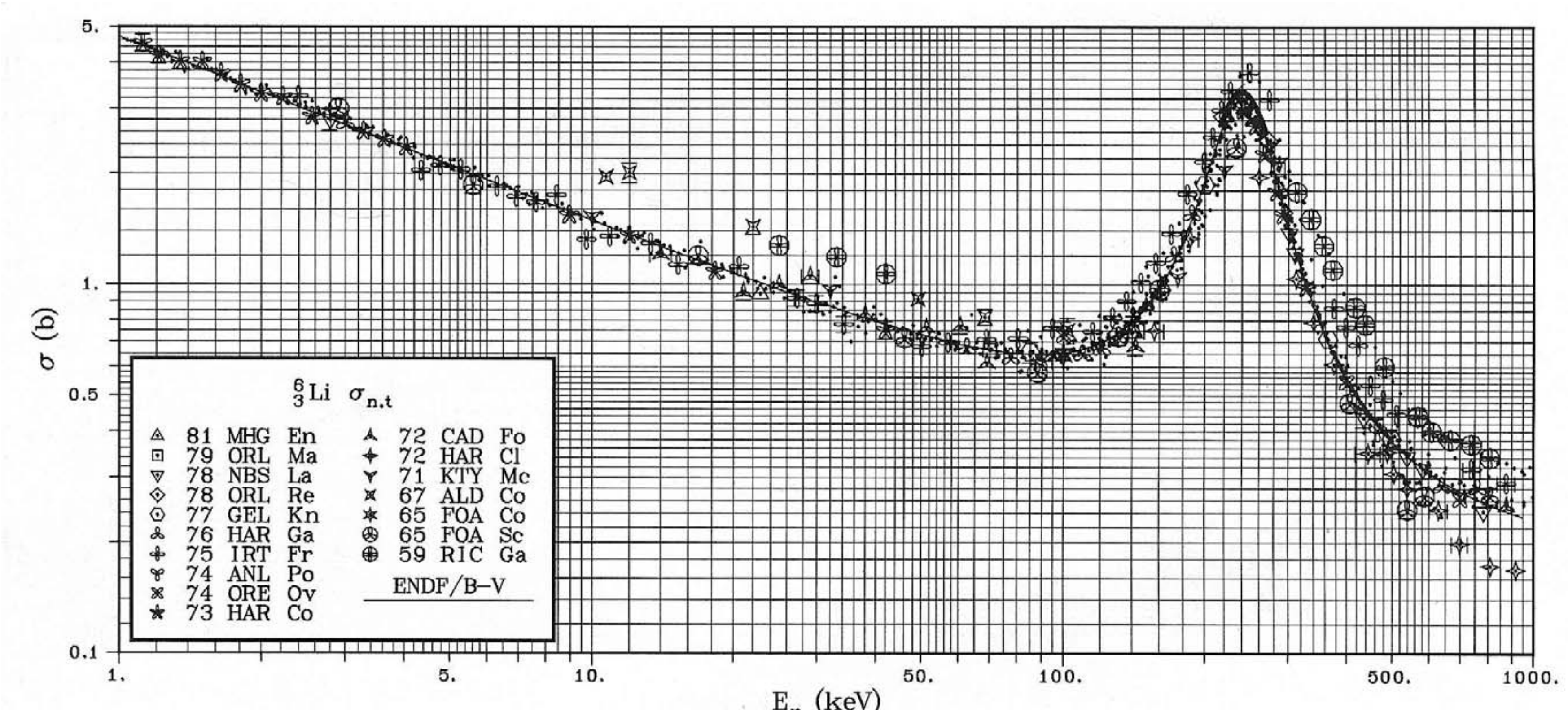
The estimated production capacity is 50-100 tons of heavy water per year.



Comparison of the Khushab heavy water plant and the Kota plant in India.

Tritium fuel production

Tritium occurs naturally but low abundance can be enhanced by accelerator or reactor based Tritium breeding through neutron capture on ^{6}**Li(n,t)**^{4}**He**.

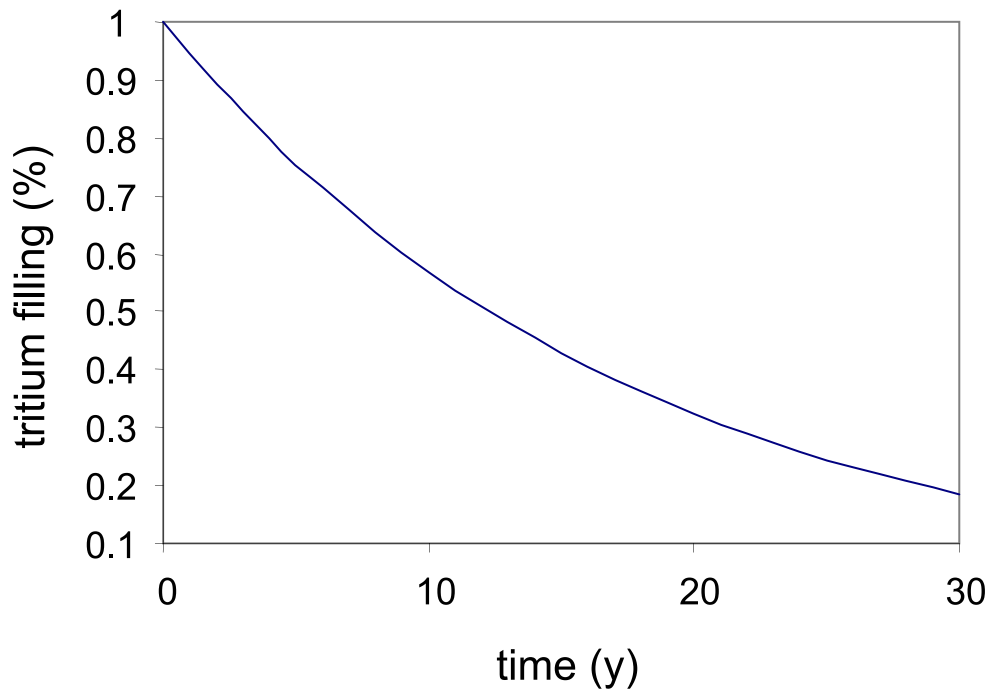


The United States has not produced tritium since 1988, when the Department of Energy Closed it's production facility site in South Carolina closed. Immediate tritium needs are being met by recycling tritium from dismantled U.S. nuclear weapons. New plans?

Maintaining weapon stock-pile

Loss of tritium fuel
in nuclear warheads
by natural decay
~5% per year!

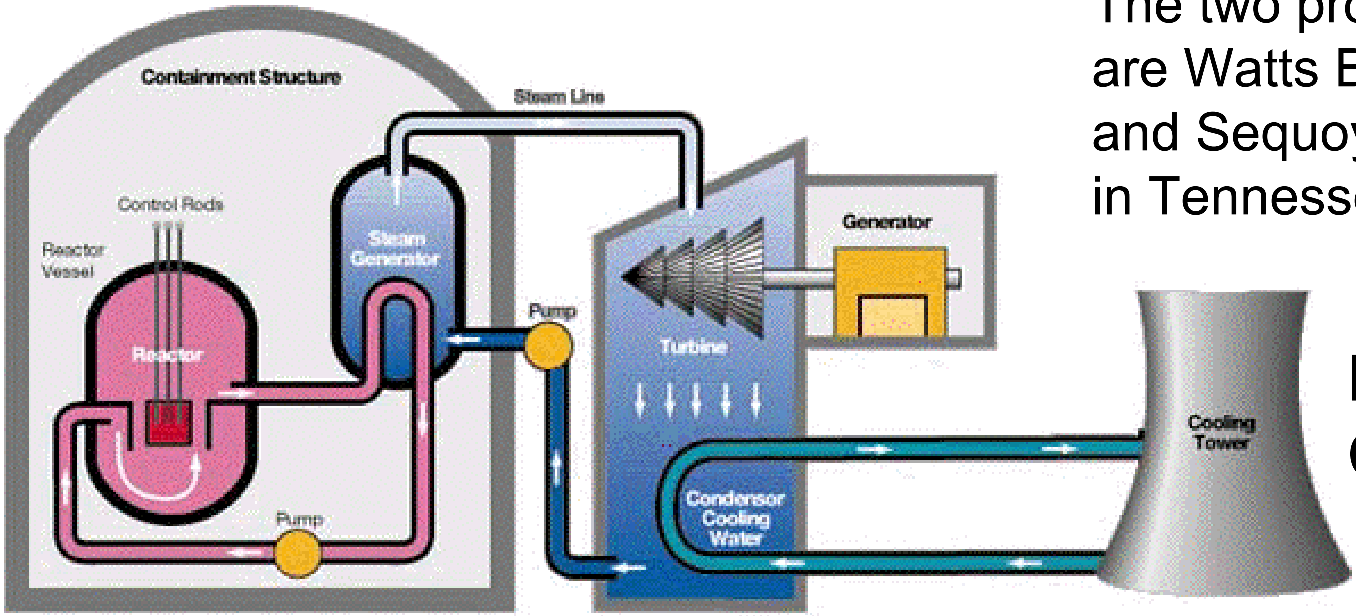
$$N_{^3H}(t) = N_{^3H}(t_0) \cdot e^{-\frac{\ln 2}{t_{1/2}} \cdot t}$$



To keep nuclear weapons stockpiles at the level prescribed by the START I (Strategic Arms Reduction Treaty), however, the United States will require a tritium supply capable of producing three kilograms of tritium each year, to go online no later than 2007.

New US tritium production plans

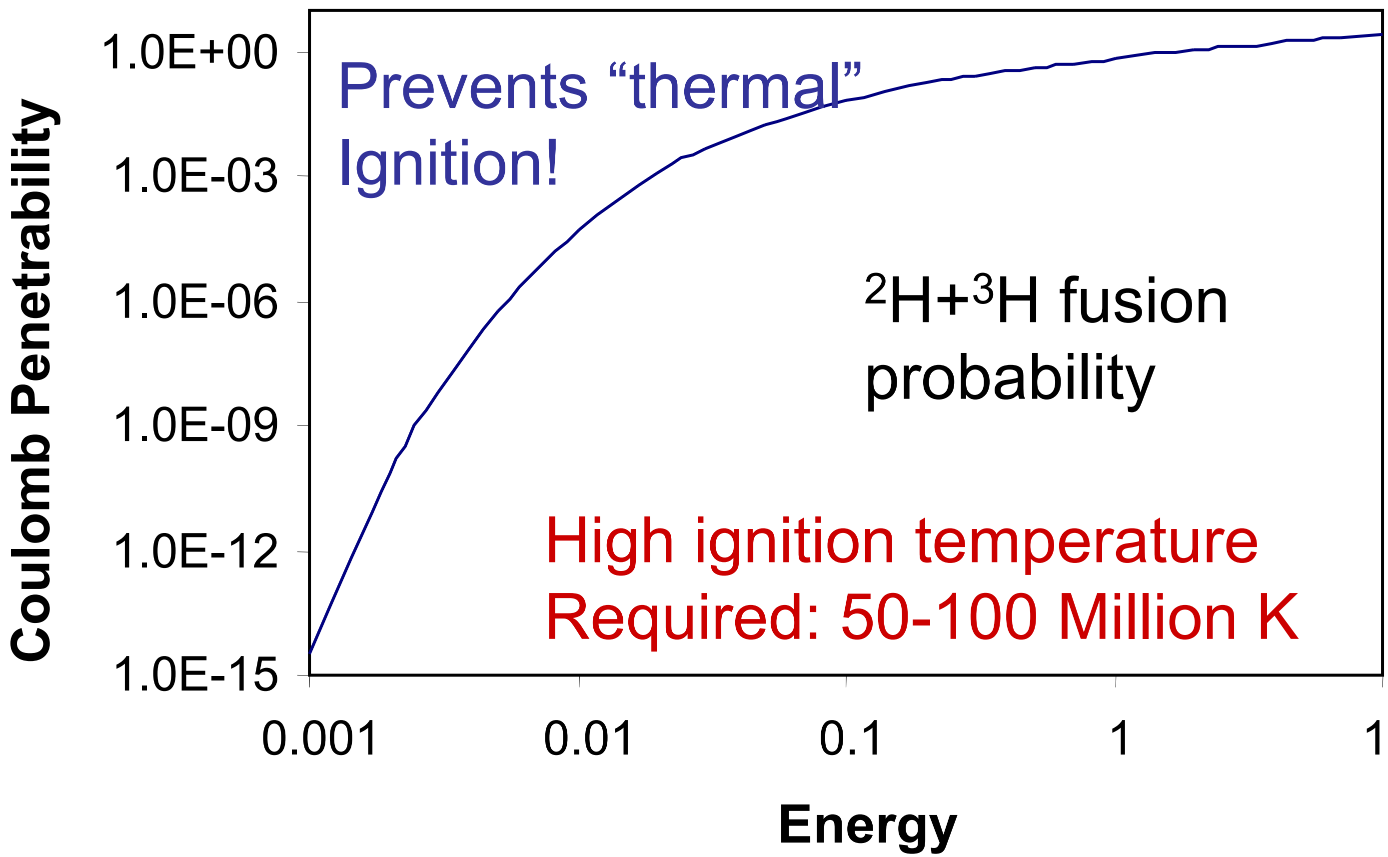
On May 22, 1996, DOE and NRC agreed on the use of commercial reactors for the production of tritium. Lithium containing control rods instead of boron rods will be used in pressurized water reactors for absorbing neutrons. Neutron capture on lithium in control rods will produce tritium. The rods are later removed from the fuel assemblies for extracting the tritium.



The two production reactors are Watts Bar Nuclear Plant and Sequoyah Nuclear Plant in Tennessee.

Non-proliferation Concerns!

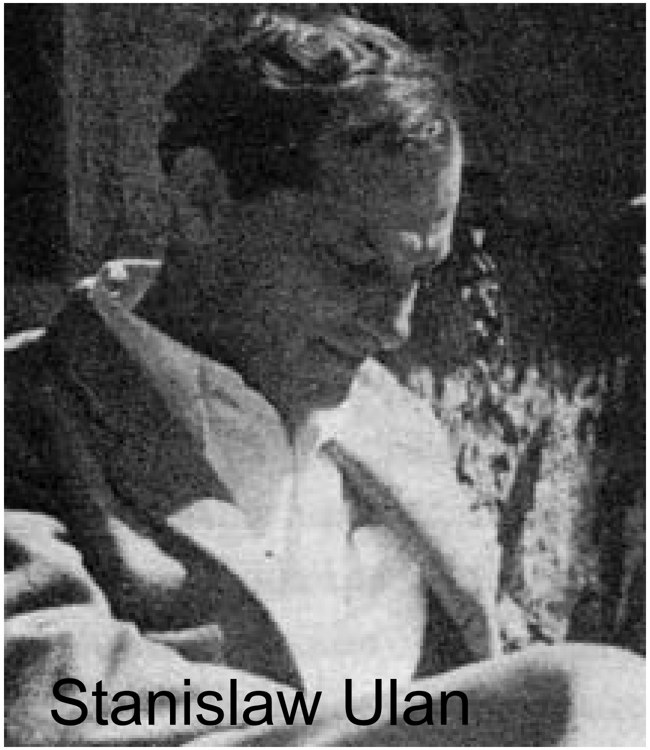
Disadvantages for hydrogen bomb



Acceleration of positive charged particles towards high energies above Coulomb barrier is necessary!

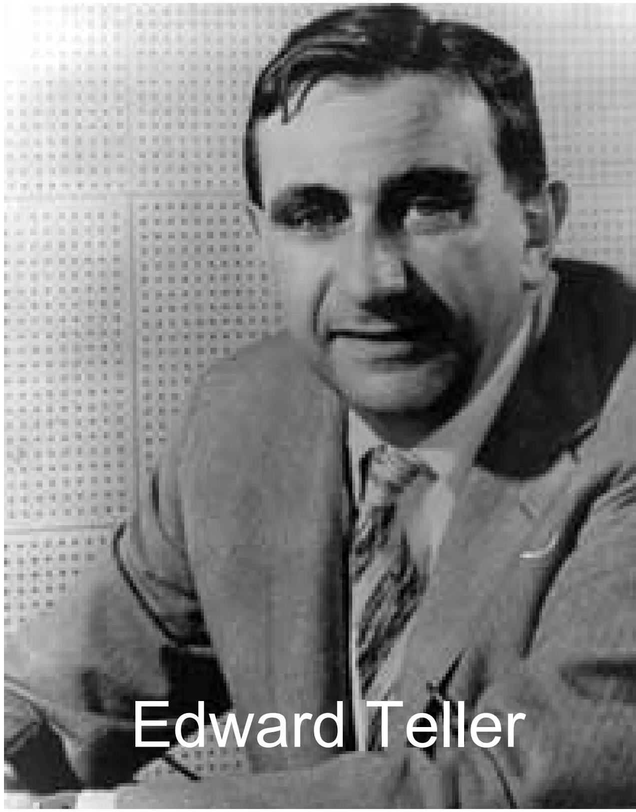
The Fathers of (US) Hydrogen Bomb

All thermonuclear weapons existing in the world today appear to be based on a scheme usually called the "Teller-Ulam" design (after its inventors Stanislaw Ulan and Edward Teller, two emigrants), or "staged radiation implosion" for a physically descriptive designation.



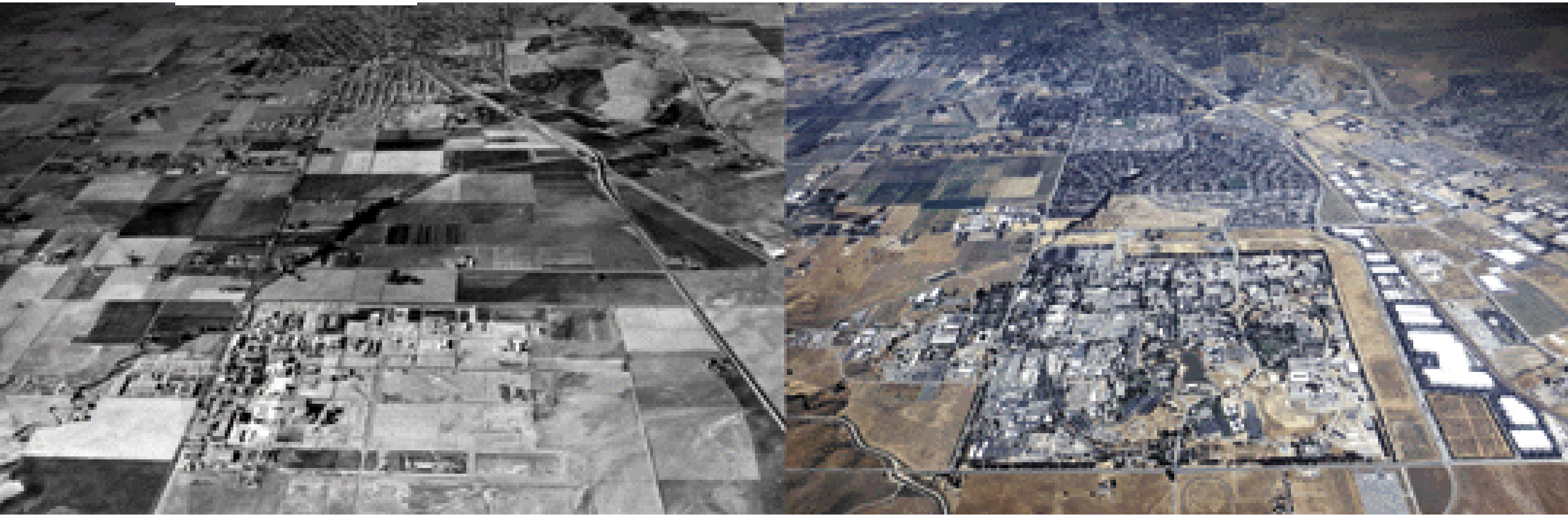
Teller, Hungarian physicist, PhD 1930 Leipzig, Germany with Heisenberg. Emigration to the US 1935. He worked with Oppenheimer in 1943 -1946 on the Manhattan project.

Ulam, Polish mathematician, came 1935 to US (Harvard), joined Manhattan project in 1943;



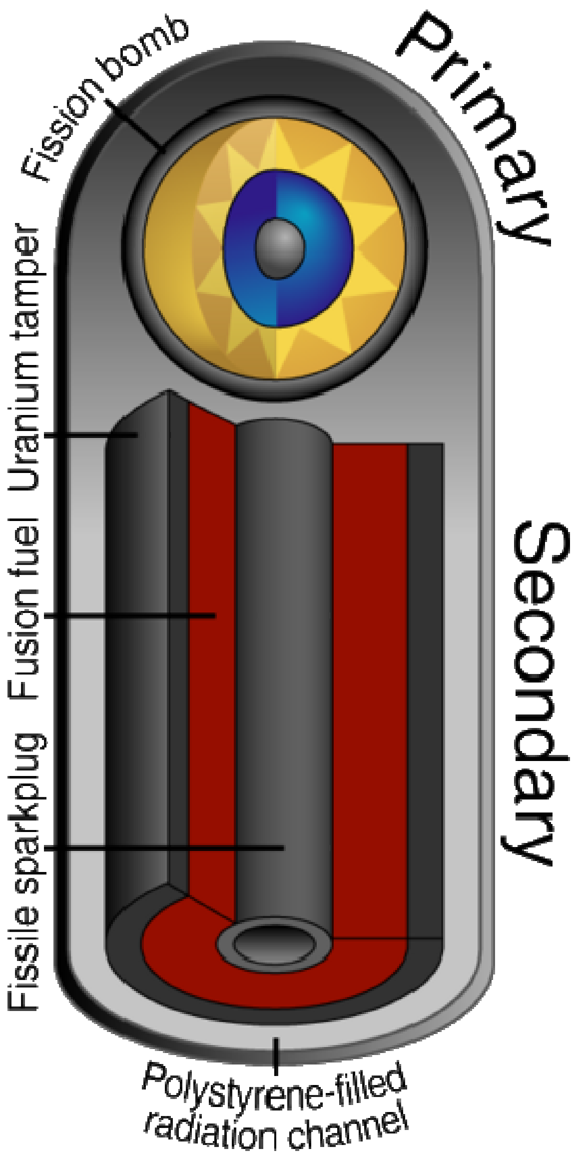
Lawrence Livermore Laboratory

Founded in 1952 in San Francisco bay area as second US weapons National Laboratory for the development and construction of H bomb. H-bomb development and test program progressed through Livermore.



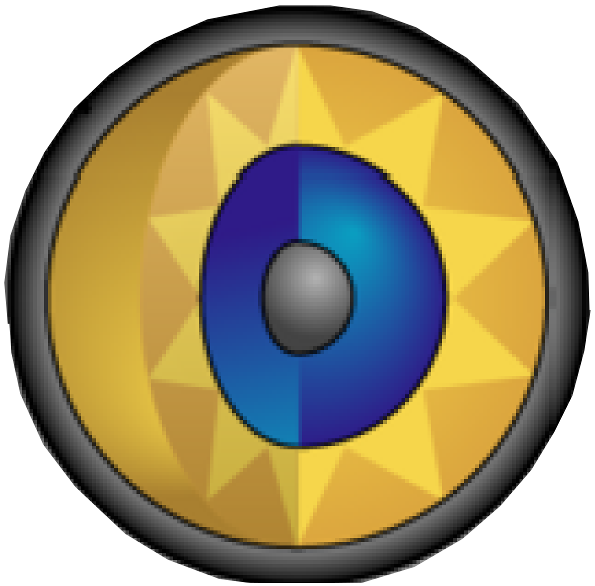
First director Edward Teller, most controversial figure in nuclear weapons history Fight with Oppenheimer about H-bomb feasibility, accusing Oppenheimer disloyalty (Oppenheimer lost security clearance in 1954). Pushed weapons test program from the early 50s to the 80s, instigated Reagan’s star war program

Ulam-Teller Design



Staged explosion of fission (primary) bomb and fusion (secondary bomb). The fission bomb is based on a regular Pu bomb design (Fat Man). Fusion device is based on d+d & d+t reaction with on-line $^{6}Li(n,t)$ tritium production and n induced fission. The fusion bomb is triggered by rapid shock driven compression (Ulam) which is enhanced by radiation pressure (Teller) from released X-ray and γ-ray flux.

Fuel

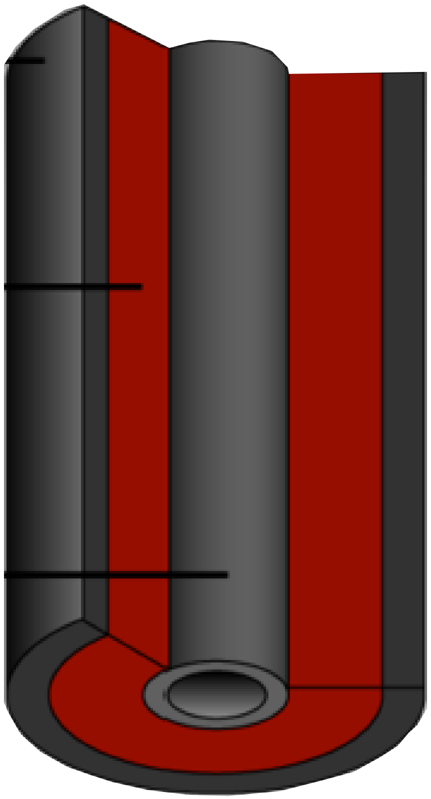


Primary Fission Device

Core: ^{239}Pu, ^{235}U,
plus $^{2}H+^{3}H$ booster

Shell: ^{238}U tamper

High explosive lenses



Secondary Fusion Device

Radiation channel

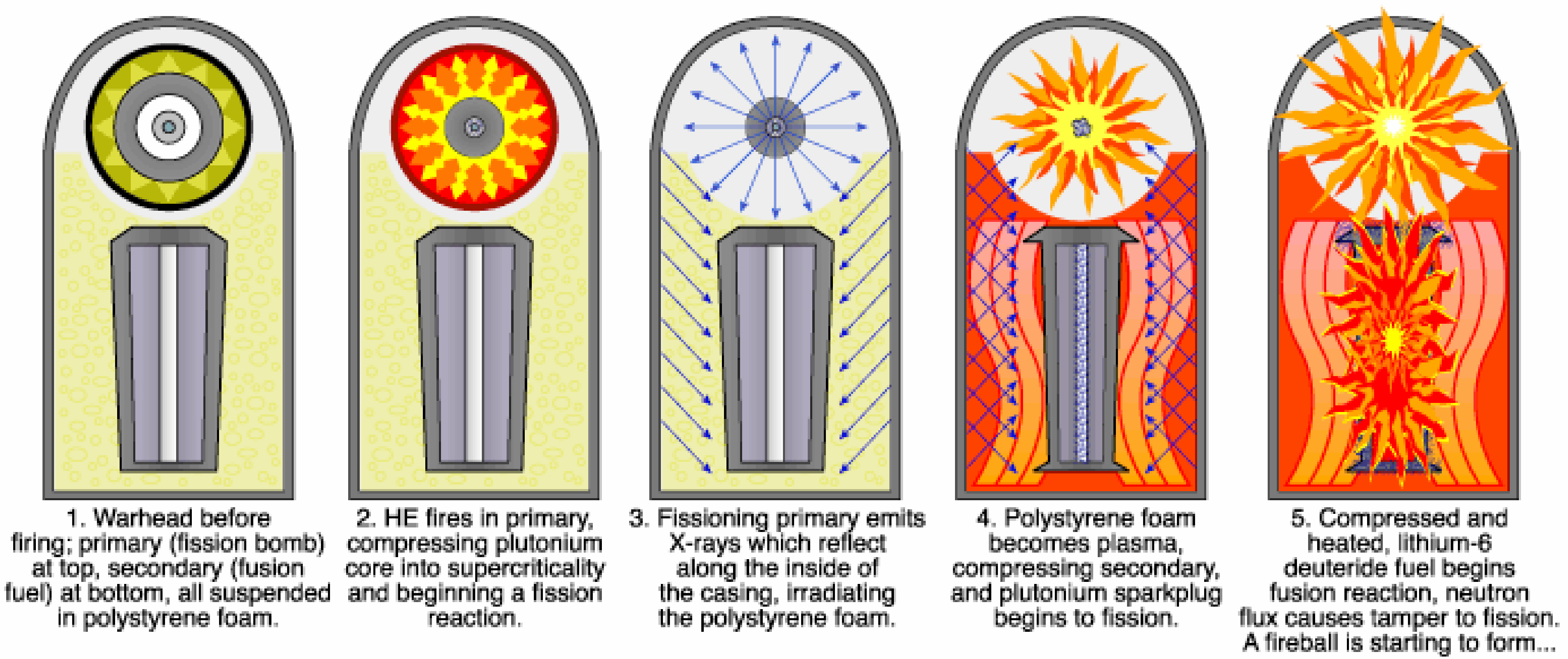
^{239}Pu sparkplug

^{6}Li, ^{2}H, ^{3}H fusion cell

^{238}U tamper

Event Sequence

The two devices are surrounded by radiation case to contain (temporarily) the energy released in primary fission driven explosion for efficient conversion into compression shock



Additional pressure from recoil of exploding shell (ablation)!

Radiation pressure P_{rad}

$$P_{rad} = \frac{F}{A} = \frac{1}{3} \cdot a \cdot T^4$$

F: force

A: Area

a: radiation constant: a=7.566·10^{-16} J m^{-3}K^{-4}

T: temperature in K …. For T≈10^{7}K

$$P_{rad} = \frac{1}{3} \cdot 7.566 \cdot 10^{-16} \cdot \left(10^7\right)^4 = 2.52 \cdot 10^{11} \left[\frac{J}{m^3} = Pa = 10^{-5}\, bar\right]$$

$$P_{rad} = 2.52 \left[Mbar\right]$$

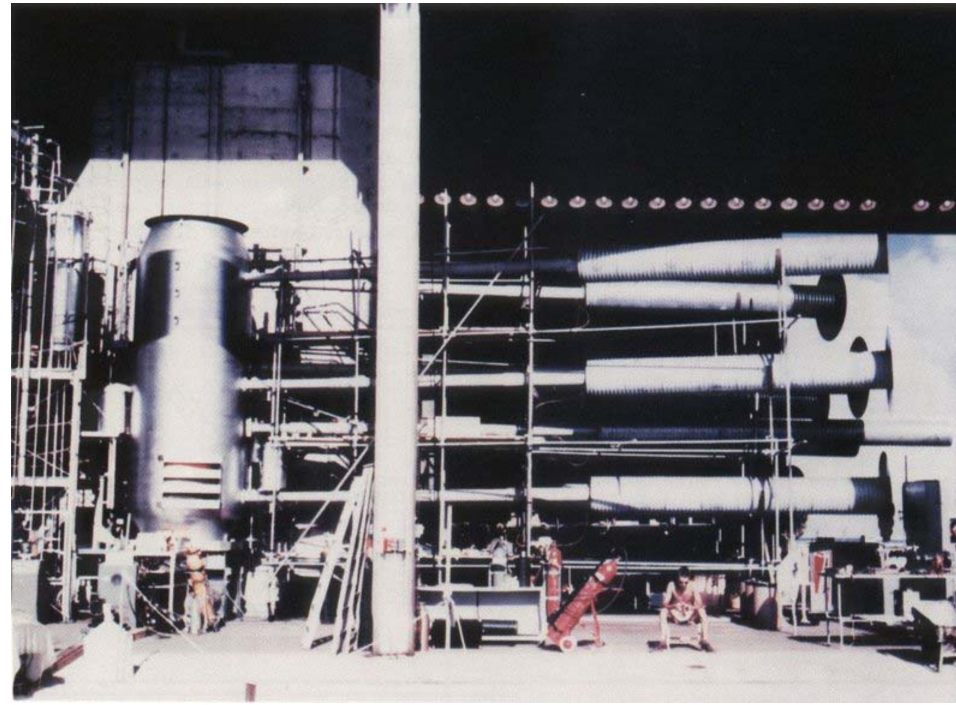
Pressure Conditions in MIKE

Comparing the three mechanisms for generating ignition pressure, we see that:

- Radiation pressure:
  - Ivy Mike: 73 million bar (7.3 TPa)
  - W-80: 1.4 billion bar (140 TPa)
- Plasma pressure:
  - Ivy Mike: (est) 350 million bar (35 TPa)
  - W-80: (est) 7.5 billion bar (750 TPa)
- Ablation pressure:
  - Ivy Mike: 5.3 billion bar (530 TPa)
  - W-80: 64 billion bar (6400 TPa)

The calculated ablation pressure is one order of magnitude greater than the higher proposed plasma pressures and nearly two orders of magnitude greater than calculated radiation pressure. No mechanism to avoid the absorbtion of energy into the radiation case wall and the secondary tamper has been suggested, making ablation apparently unavoidable.

Mike

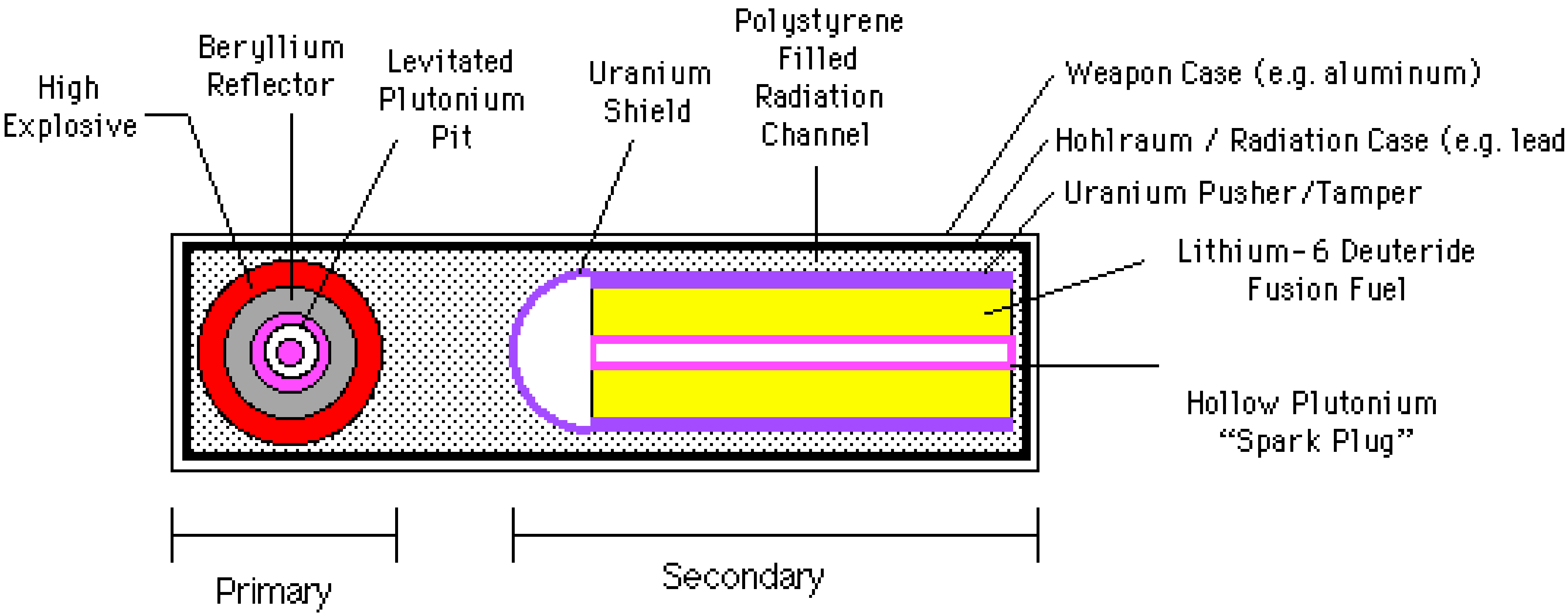


The "Mike" device was essentially a very large cylindrical thermos flask for holding the cryogenic deuterium fusion fuel, with a regular fission bomb (the "primary") at one end; the latter was used to create the conditions for starting the fusion reaction. The primary was a boosted fission bomb in a separate space atop the assembly.
The "secondary" fusion stage used liquid deuterium because this fuel simplified the experiment, and make the results easier to analyze. Running down the center of the flask which held it was a cylindrical rod of plutonium (the "sparkplug") to ignite the fusion reaction. Surrounding this assembly was a five-ton natural uranium "tamper". The interior of the tamper was lined with sheets of lead and polyethylene foam, which formed a radiation channel to conduct X-rays from the primary to secondary. The outermost layer was a steel casing 10-12 inches thick. The entire "Sausage" (as it was nicknamed) assembly measured 80 inches in diameter and 244 inches in height and weighed about 60 tons.
The entire Mike device (including cryogenic equipment) weighed 82 tons, and was housed in a large corrugated-aluminium building called a "shot cab" which was set up on the Pacific island of Elugelab, part of the Enewetak atoll.

- First staged fusion explosion occurred on Eniwetok Atoll on Oct. 31, 1952.
- Mike used liquid deuterium as a fuel.
- The output of 10.4 megatons of TNT exceeded all of the explosives used in WW II including both atomic bombs.

Mike consisted of a cylinder about 20 ft high, ~7 ft wide, weighing 164,000 lb; The detonation of Mike left underwater crater 6240 feet wide and 164 ft deep. Mike created a fireball 3 miles wide; the 'mushroom' cloud rose to 57,000 ft in 90 seconds, and topped out in 5 minutes at 135,000 ft , with a stem eight miles across. The cloud eventually spread to 1000 miles wide, with a stem 30 miles across. 80 million tons of soil were lifted into the air by the blast."

Modern Thermonuclear Warhead



The bomb design is based on a bomb casing containing implosion fission bomb and a cylinder casing of ^{238}U (tamper). Within the tamper is the ^{6}LiD (fuel) and a hollow rod of ^{239}Pu in the center of the cylinder. Separating the cylinder from the implosion bomb is a shield of ^{238}U and plastic foam that fills the remaining space in the bomb casing.

Modern H-bomb design

The detonation of the trigger bomb will cause the following sequence of events:

1. The fission bomb implodes, emitting X-rays.
2. X-rays heat the interior of the bomb and the tamper; which prevents premature detonation of the fuel.
3. The heat causes the tamper to expand and burn away, exerting pressure inward against the lithium deuterate. The lithium deuterate is squeezed by about 30-fold.
4. The compression shock waves initiates fission in the plutonium rod.
5. The fissioning rod gives off radiation, heat and neutrons.
6. The neutrons enter the lithium deuterate, and generate tritium.
7. The combination of high temperature and pressure is sufficient for tritium-deuterium and deuterium-deuterium fusion reactions to occur, producing more heat, radiation and neutrons.
8. The neutrons from the fusion reactions induced fission in the uranium-238 pieces from the tamper and shield.
9. Fission of the tamper and shield pieces produced even more radiation and heat.
10. The bomb explodes.

Multiple stage design possible!

The Castle-Bravo Test

Soviet Response 1955

RDS-37: The First Soviet Superbomb ("True H-Bomb") Test

November 22,1955; Semipalatinsk Test Site, Kazakhstan

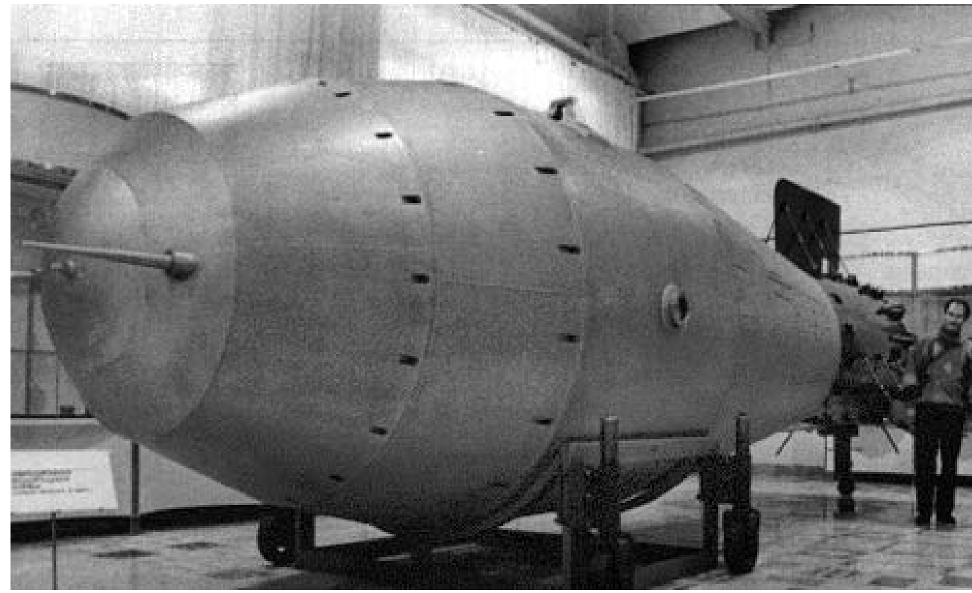
The bomb exploded underneath an inversion layer, which focused the shock back toward the ground unexpectedly. This refracted shock wave did unanticipated collateral damage, killing three people from a building collapse.

The Cold War and Nuclear Arms Race

I remember President Kennedy once stated... that the United States had the nuclear missile capacity to wipe out the Soviet Union two times over, while the Soviet Union had enough atomic weapons to wipe out the Unites States only once... When journalists asked me to comment... I responded, "Yes, I know what Kennedy claims, and he's quite right. But I'm not complaining... We're satisfied to be able to finish off the United States first time round. Once is quite enough. What good does it do to annihilate a country twice? We're not a bloodthirsty people."

Nikita Khrushchev - 1974

Ridiculous Dimensions



Biggest US bomb:
1MT TNT MARK-17

Biggest Soviet Bomb:
50 MT Tsar Bomb

The big bomb never had any military significance. It was a demonstration of force, part of the superpower game of mutual intimidation. This was the main goal of the unprecedented test. Super-weapons are rejected by contemporary military doctrine, and the proposition that “now we have even more powerful warheads” is simply ridiculous.

Attempts for stopping the race

The Baruch Plan 1946; Bernard Baruch, U.S. representative to the U.N. Atomic Energy Commission, seemed to propose a radical plan to put atomic weapons under strict U.N. control. The United States was at the time the only nuclear power in the world. Under the so-called Baruch Plan, the United States would relinquish its atomic monopoly in favor of the creation of a new U.N. Atomic Development Authority, which would become the sole body in the world that could legally possess nuclear arms. Violators were subject to preemptive measures including a nuclear strike. The Soviet Union opposed the Baruch Plan, and in 1949 the first Soviet atomic bomb was detonated.

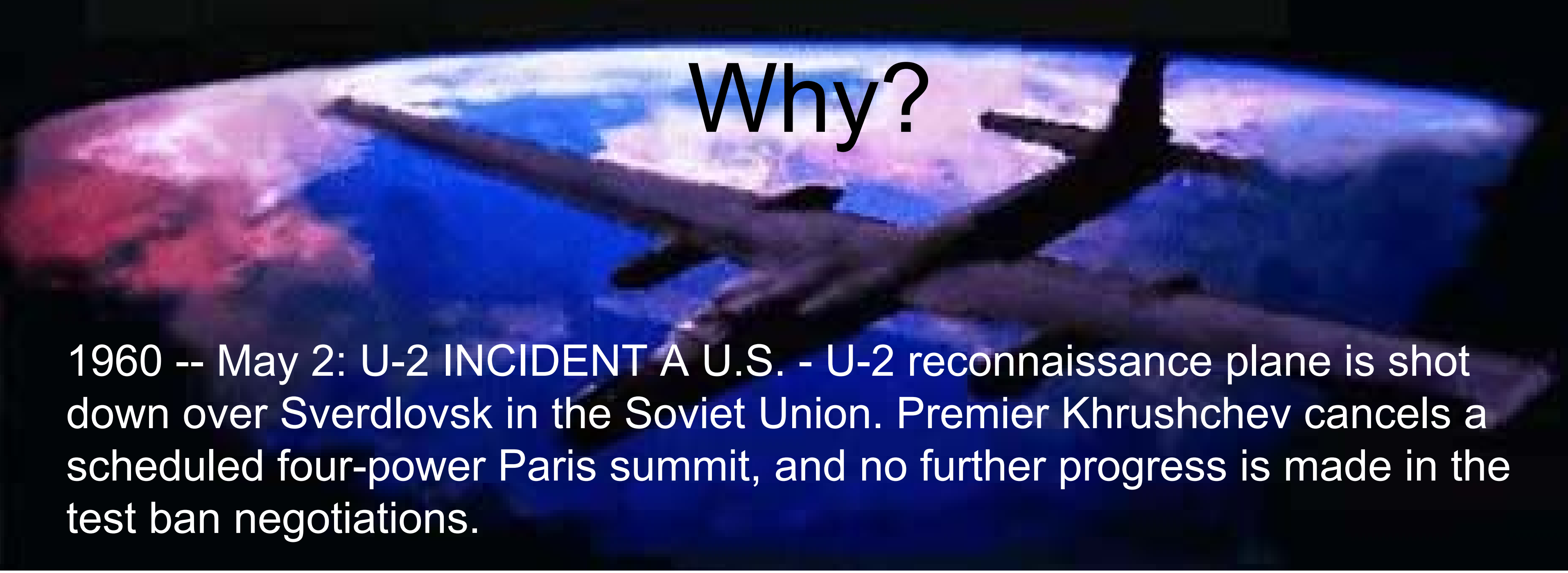
UN proposal for nuclear disarmament 1955; Soviet Union accepted the plan, after achieving hydrogen weapon success. In 1956 US rejected the U.N. proposed plan for disarmament and identified nuclear weapons as a “powerful deterrent to war”

Voluntary Test Moratorium: 1958-1961
October 10, 1963; Limited Nuclear Test Ban Treaty

Towards a Test Ban treaty?

The three nuclear powers refrained from testing beginning 1958. This voluntary "moratorium" was marked by several public statements of intent, by the United States, the United Kingdom, and the Soviet Union, in varying degrees of specificity and with various caveats. At the end of December 1959 President Eisenhower announced that the United States would no longer consider itself bound by the "voluntary moratorium" but would give advance notice if it decided to resume testing. The Soviet Government stated on August 28 and Premier Khrushchev repeated on December 30, 1959, that the Soviet Union would not resume testing if the Western powers did not. France conducted its first test on February 13, 1960, two more later in the year, and a fourth on April 25, 1961. On May 15, 1961, the Soviet Government stated that if France continued testing, the Soviet Union might be compelled to test. On August 30, 1961, although neither the United States nor the United Kingdom had resumed testing and France had not continued to test, the Soviet Union announced that it would resume testing. It did so on September 1, thus ending the moratorium. The United States resumed testing two weeks later.

Why?



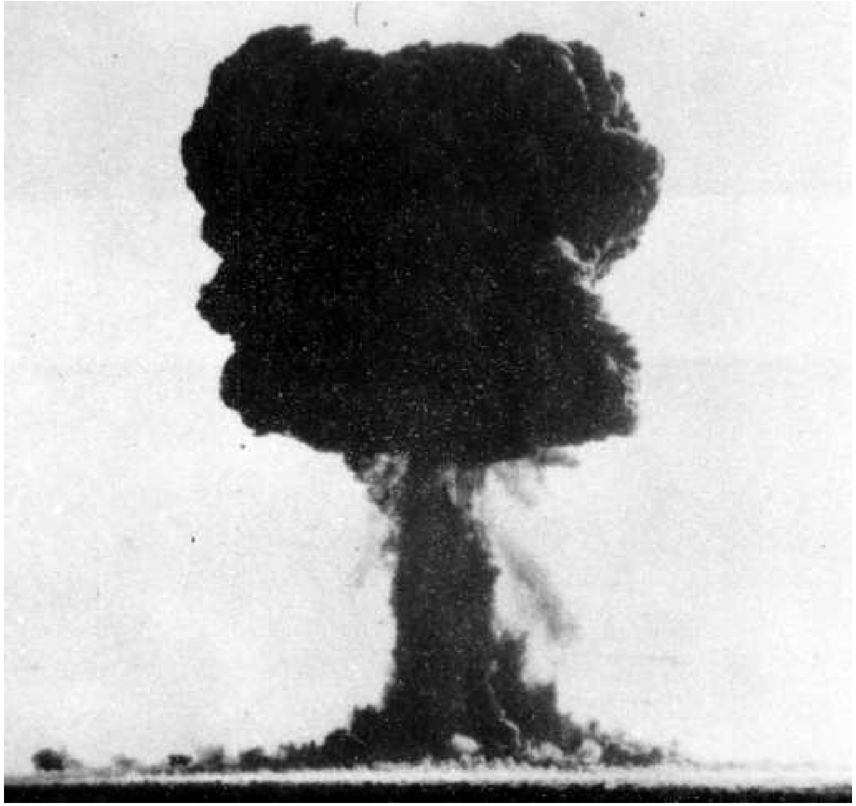
1960 -- May 2: U-2 INCIDENT A U.S. - U-2 reconnaissance plane is shot down over Sverdlovsk in the Soviet Union. Premier Khrushchev cancels a scheduled four-power Paris summit, and no further progress is made in the test ban negotiations.

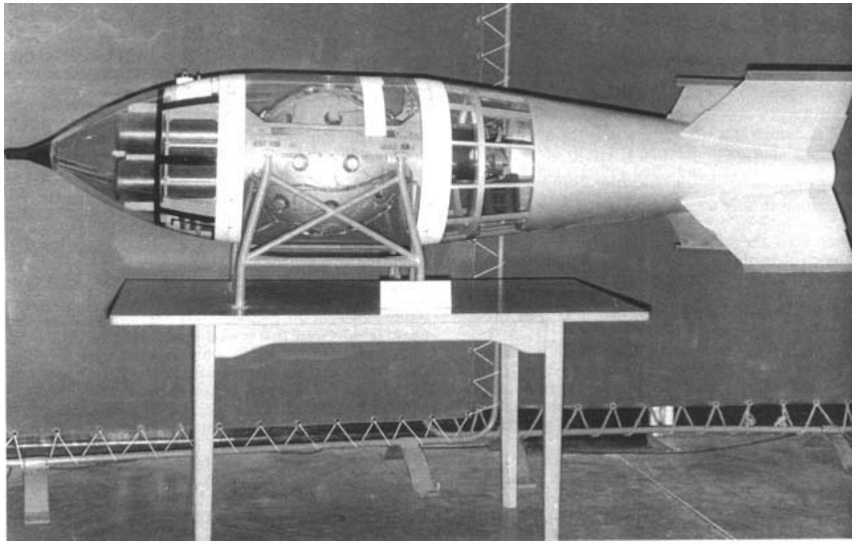
1960 -- February 13: FIRST FRENCH NUCLEAR TEST France explodes its first nuclear device at a test site in the Sahara Desert.

1961 -- September 1: RESUMPTION OF SOVIET NUCLEAR TESTING - Arguing that increased international tensions and the French nuclear test program have created a changed security environment, the Soviet Union resumes atmospheric nuclear testing.

Proliferation beyond the "Superpowers"

After Soviet Union in 1949, the first successful British test of a pure fission based 10 kT bomb (Totem 1) took place on October 14, 1953 at Emu Field, Australia.

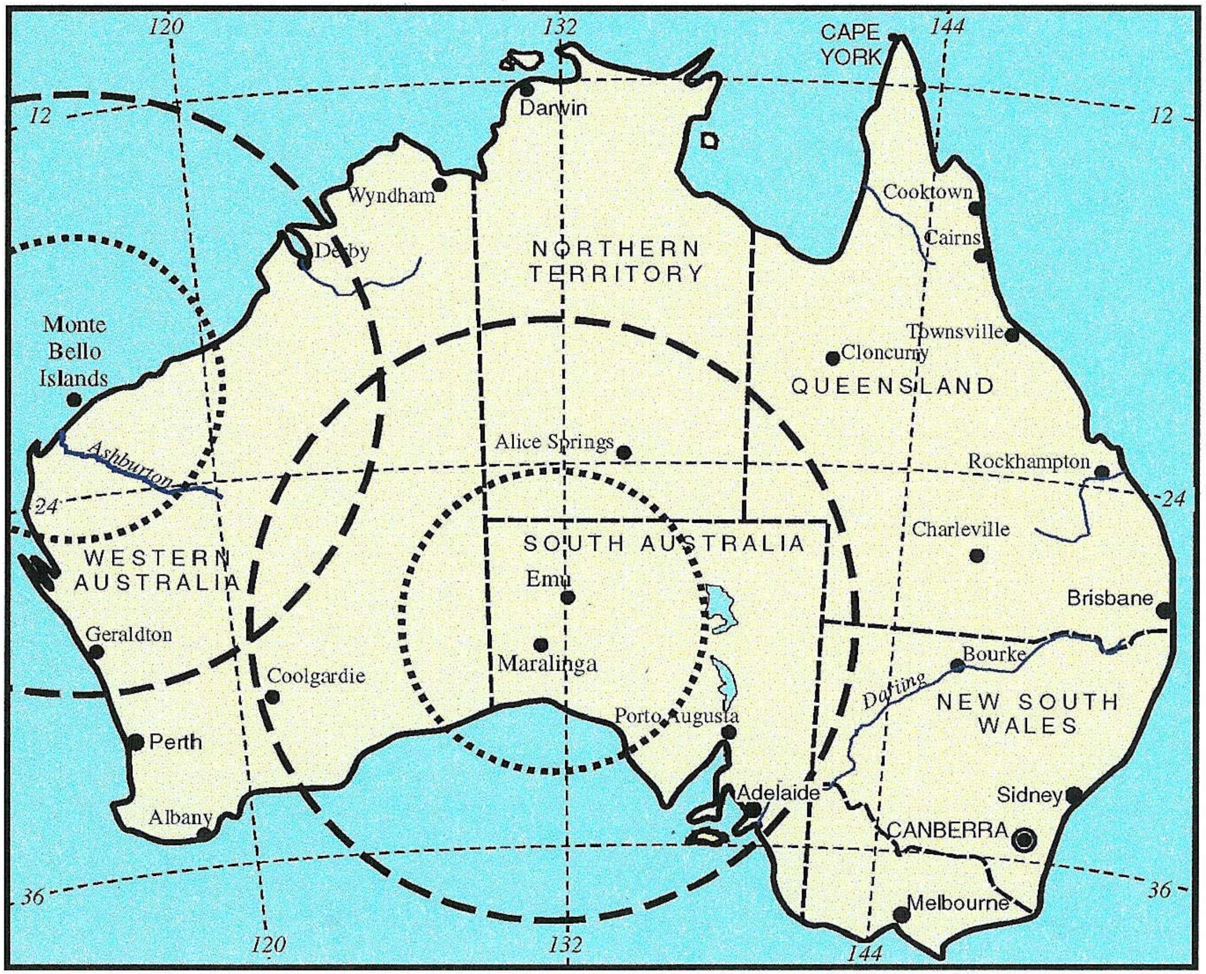




The free fall bomb (Blue Danube) was the first nuclear weapon stockpiled by Britain, and going into service in November 1953

1954 Winston Churchill decided that Britain should go ahead with H-bomb development, that is, to replicate the U.S. achievement.

EMU field, British test site



Maralinga, Emu and Monte Bello test sites.
The inner dotted circle indicates a distance of 500 km, the outer dashed circle 1,000 km from the test sites.

Proliferation after the 1963 test ban

In 1949 and 1952 France build its first reactors which could be used For ^{239}Pu breading. Uranium ores were discovered in France in 1951. French nuclear weapon program began in earnest in 1956, after the humiliating defeat at Dien Bien Phu and loss of French Indochina.

Lack of US support during Suez crisis, France decided to develop its Independent military and nuclear force structure (Force de Frappe). The first French nuclear test, code-named *Gerboise Bleue (60-70KT)*, was detonated at on February 13 1960 at Reggane in Algeria. After Algeria gained independence in 1966, the french testing program moved to the Mururoa and Fangataufa Atolls in the South Pacific.

The China Program

China began developing nuclear weapons in the late 1950s with Soviet Union assistance. Of the assistance provided, most significant to China's future nuclear capability were an experimental nuclear reactor, facilities for processing uranium, a cyclotron, and some equipment for a gaseous diffusions plant.

When Sino-Soviet relations cooled in the late 1950s and early 1960s, the Soviet Union withheld plans and data for an atomic bomb, abrogated the agreement on transferring defense technology, and began the withdrawal of Soviet advisers in 1960. Despite the termination of Soviet assistance, China committed itself to continue nuclear weapons development to break "the superpowers' monopoly on nuclear weapons," to ensure Chinese security against the Soviet and United States threats, and to increase Chinese prestige and power internationally.

China made remarkable progress in the 1960s in developing nuclear weapons. In a thirty-two-month period, China successfully exploded its first atomic bomb (October 16, 1964) at Lop Nor (Takla Makan desert), launched its first nuclear missile (October 25, 1966), and detonated its first hydrogen bomb (June 14, 1967).

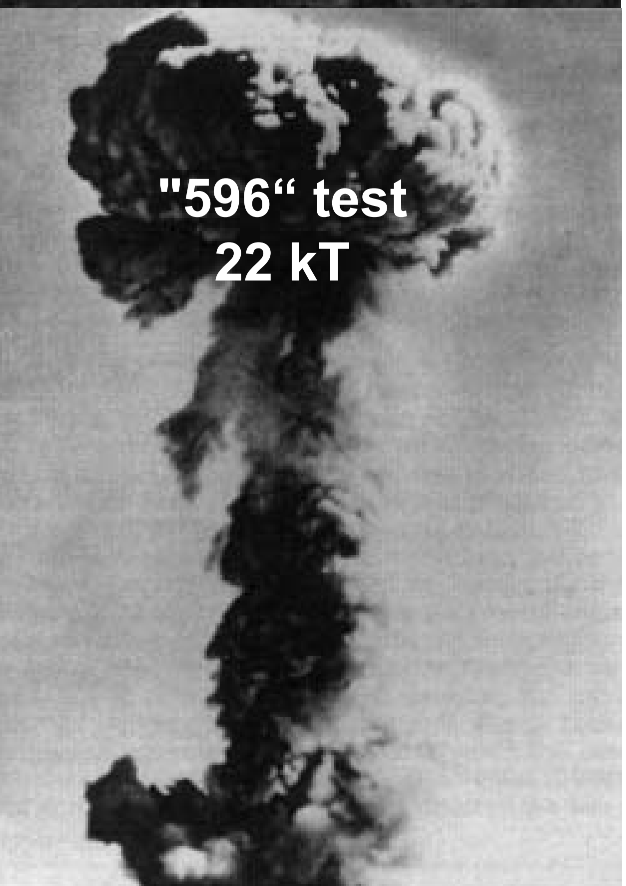
The first successful Chinese Bomb

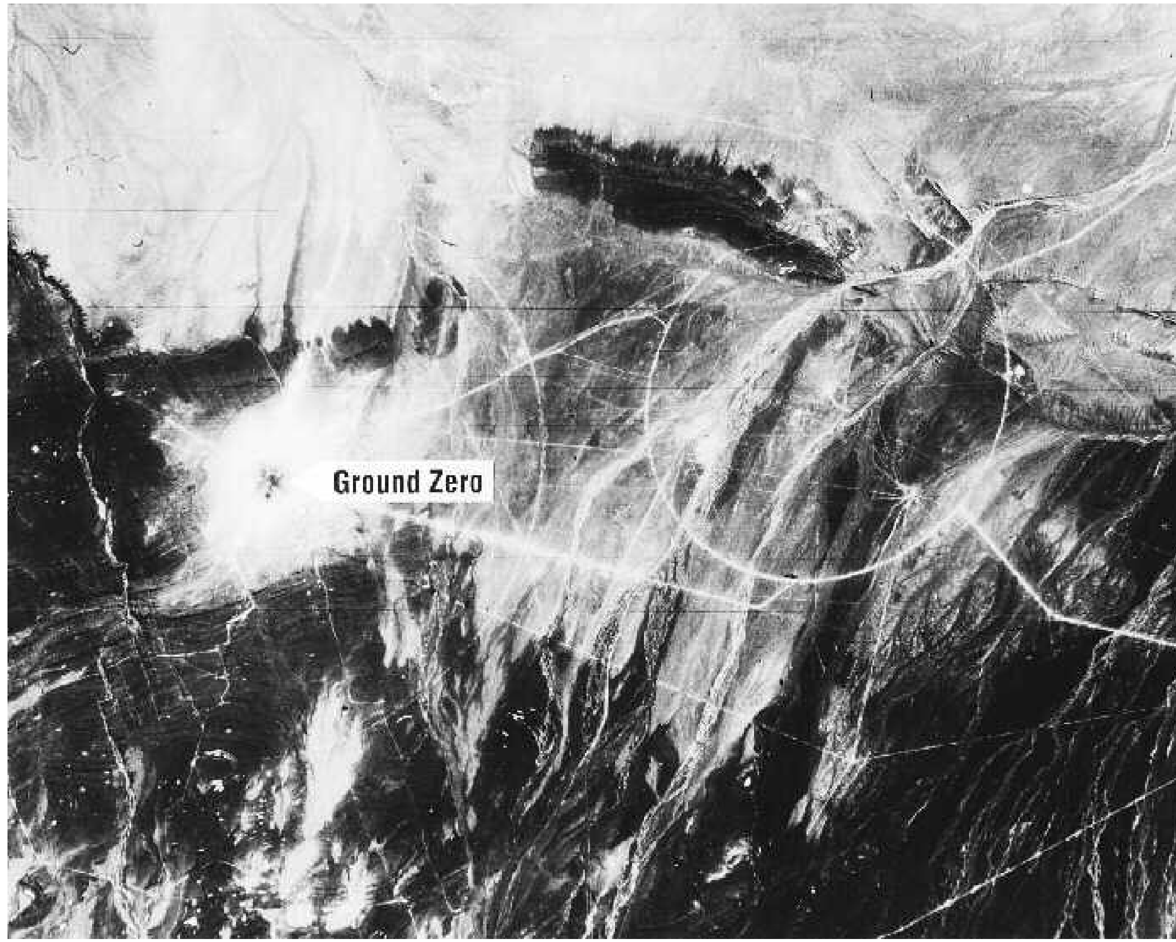
Soviet and Chinese test sites

Lop Nor and Semipalatinsk test sites.

The inner dotted circle indicates a distance of 500 km, the outer dashed circle 1,000 km from the test sites.

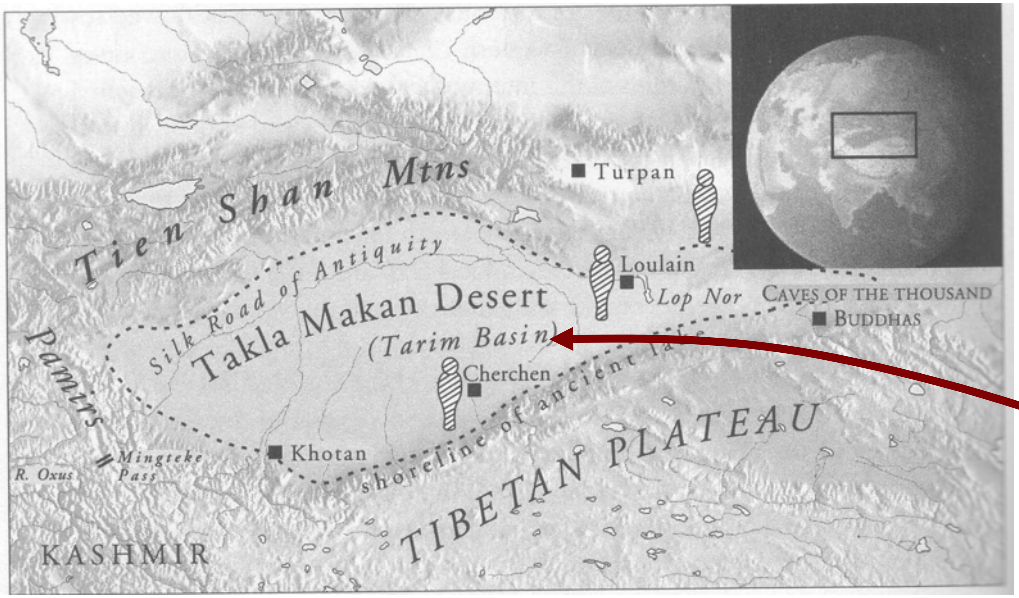
The Lop Nor Tests

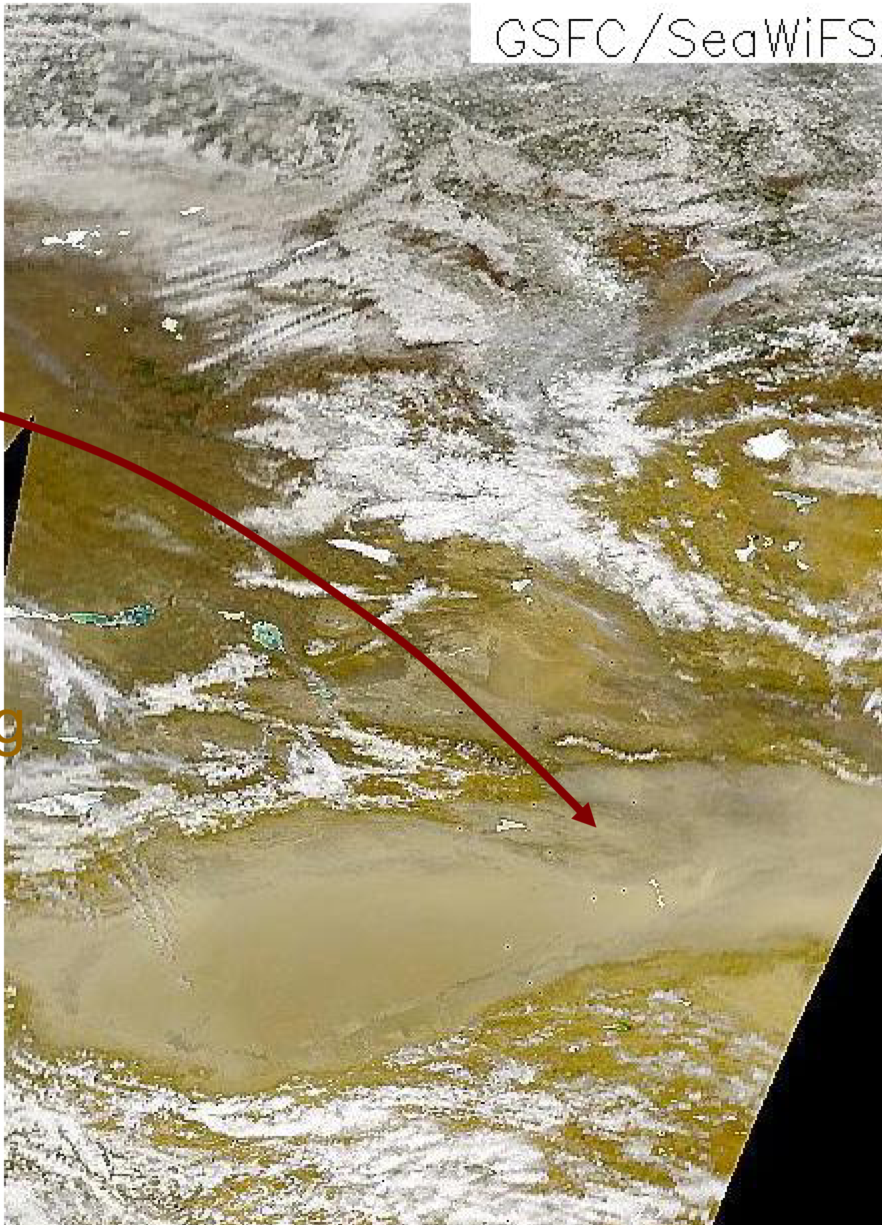




The Lop Nor Nuclear Test Range four days after the test of "596". Image from a KH-4 Corona intelligence satellite.

Tarim Basin in Takla Makan Desert

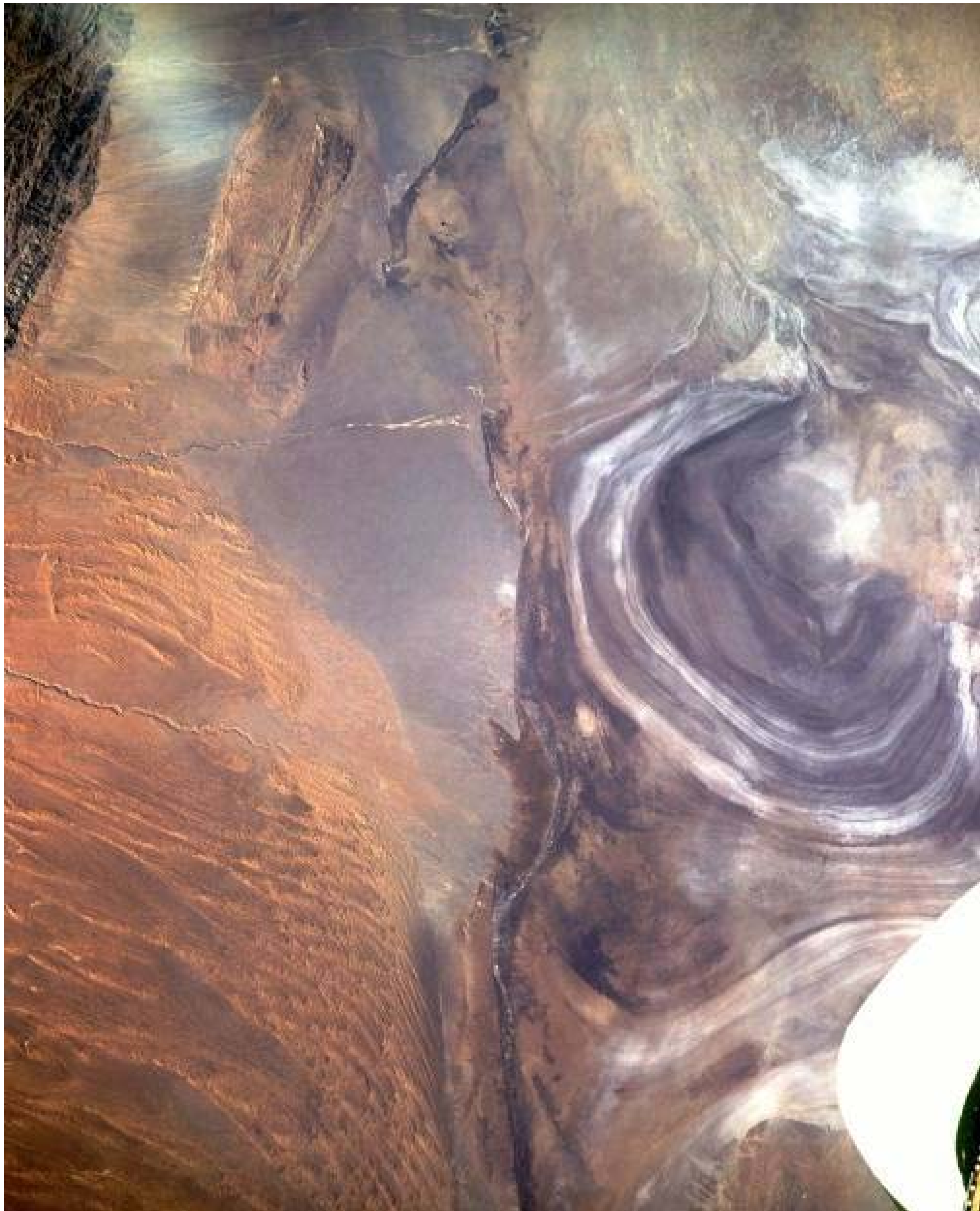




About 3000 ft Basin in Takla Makan was location of extensive lake during last ice age. lake evaporated within the subsequent 10000 years. Early discoverers, Marco Polo, reported on lake existence, 19th century travelers, Sven Hedin could only confirm a saline lake in the desert.

Lop Nor in Takla Makan

Lop Nor, on the east edge of the Tarim Basin in China's Zinjiang Province. Structure was created by water level changes within the former lake. Concentric rings formed as water evaporated from the lake and left mineral deposits, including highly reflective salts, along the new shoreline. The former lake now resembles a giant ear. Visible are a small plateau ~ 3000 ft above the terrain south of Lop Nor and extensive sand dunes and sand ridges to the southeast.



Existence of Tarim basin lake civilization confirmed by 2001 Chinese expedition

Chinese nuclear sites today

Smaller Nations “under threat”

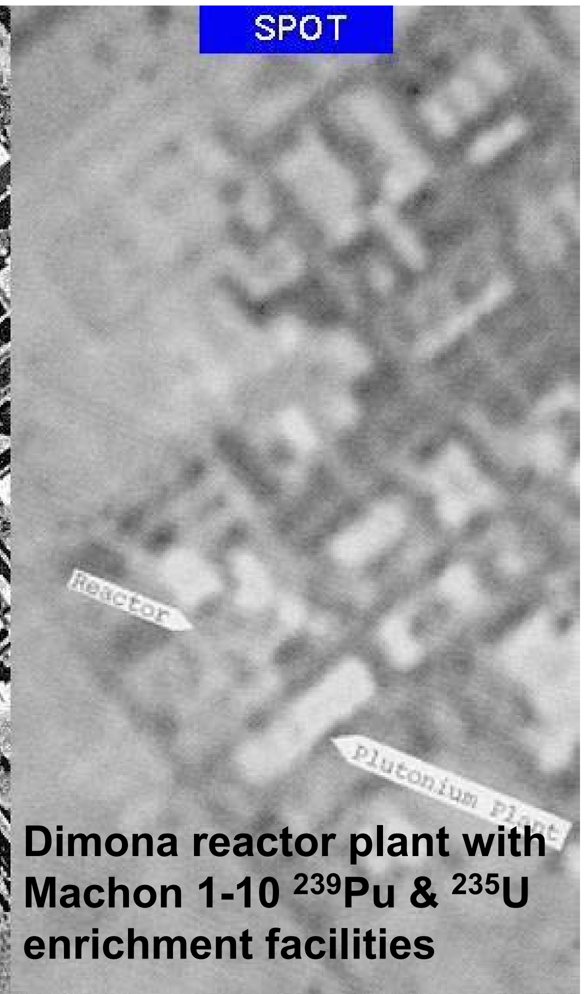
The Suez crisis triggered the **Israel** nuclear weapons program. Already in 1953, Israeli Prime Minister Ben-Gurion had ordered the development of nuclear weapons. Six weeks before the Suez Canal operation in 1956, Israel approached France for assistance in building a nuclear reactor Dimona . Reactor was completed in 1964 and declared to be for peaceful purposes. The United States government did not encourage or approve of the Israeli nuclear program, it also did nothing to stop it. In early 1968, the CIA issued a report concluding that Israel had started production of nuclear weapons.

South Africa’s quest for a nuclear deterrent began with research for peaceful nuclear explosives (PNEs) and reactor development in 1969. Pretoria initially would not confirm it was developing, or possessed, nuclear weapons, but it had large natural deposits of uranium, uranium enrichment facilities and the necessary technological infrastructure. These projects were undertaken with some cooperation from Israel. Initial tests in 1975 stopped by USSR and US cooperation but a flash over the Indian Ocean was detected by an US satellite in September 1979 and was suspected of being a nuclear test.

1971 US spy plane

The “secret” Israel program

Conclusion that by 1996 Israel had produced 330-580 kg of plutonium for a stockpile of 80-150 weapons



Dimona reactor plant with Machon 1-10 ^{239}Pu & ^{235}U enrichment facilities

The “Mordechai Vanunu” Case

Most information by Mordechai Vanunu who managed to take and publicize 60 photos, later kidnapped by Mossad and brought to Israel for trial.

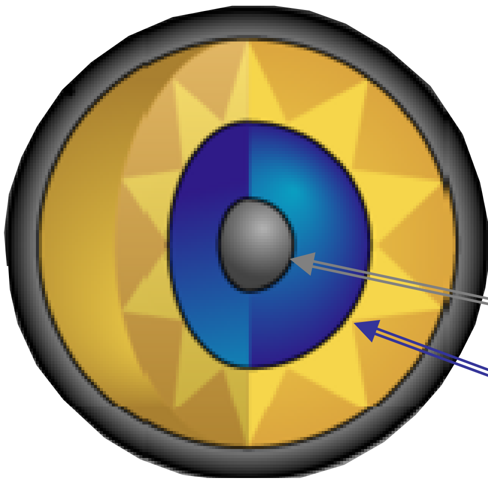
THE SUNDAY TIMES

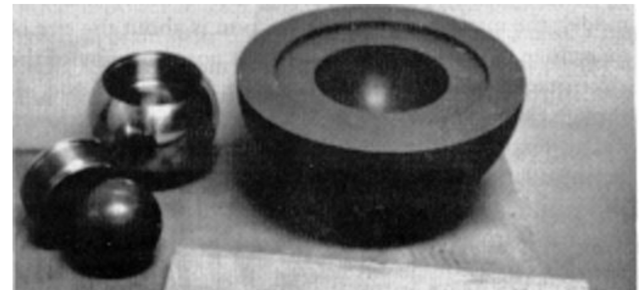
evealed: the secrets o
rael’s nuclear arsena

October 5, 1986

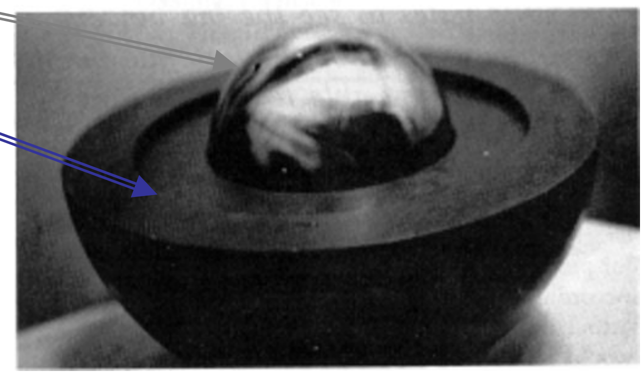
- ❑ Convicted in secret trial in 1988 to 18 years imprisonment.
- ❑ Released in 2004, but frequently rearrested in 2004 and 2005
- ❑ Prevented to emigrate from Israel in the name of National Security

Pu Bomb Model





Bomb assembly model



Glove Box photo at Dimona facility

Core: ^{239}Pu (with ^{235}U?)

Tamper: ^{238}U for ^{239}Pu enhancement

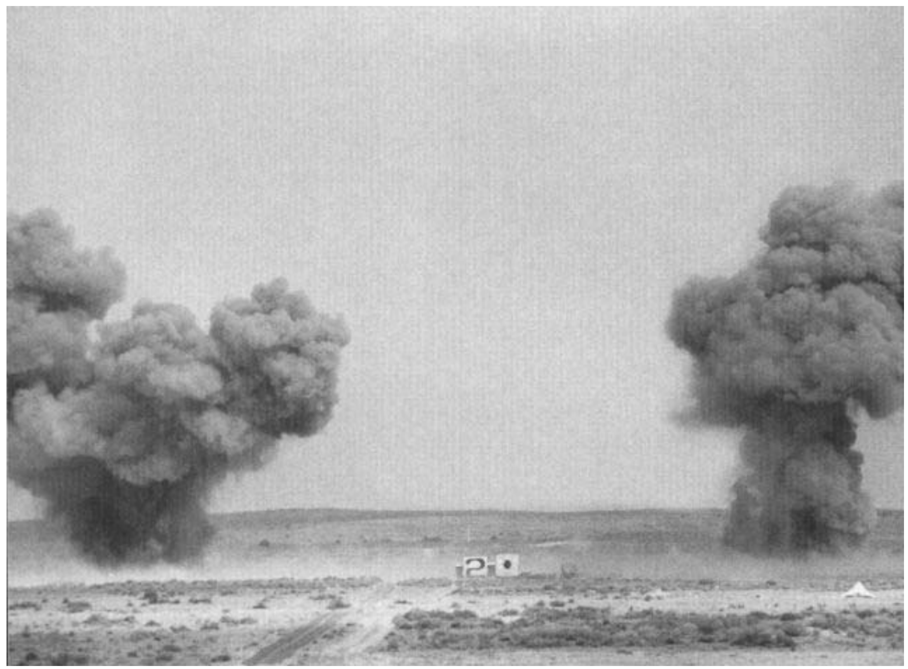
^{6}LiD component for fusion enhancement?

India & Pakistan

Deep resentment and hate since 1948 independence and separation of the Indian Subcontinent into a Muslim and a Hindu dominated part.

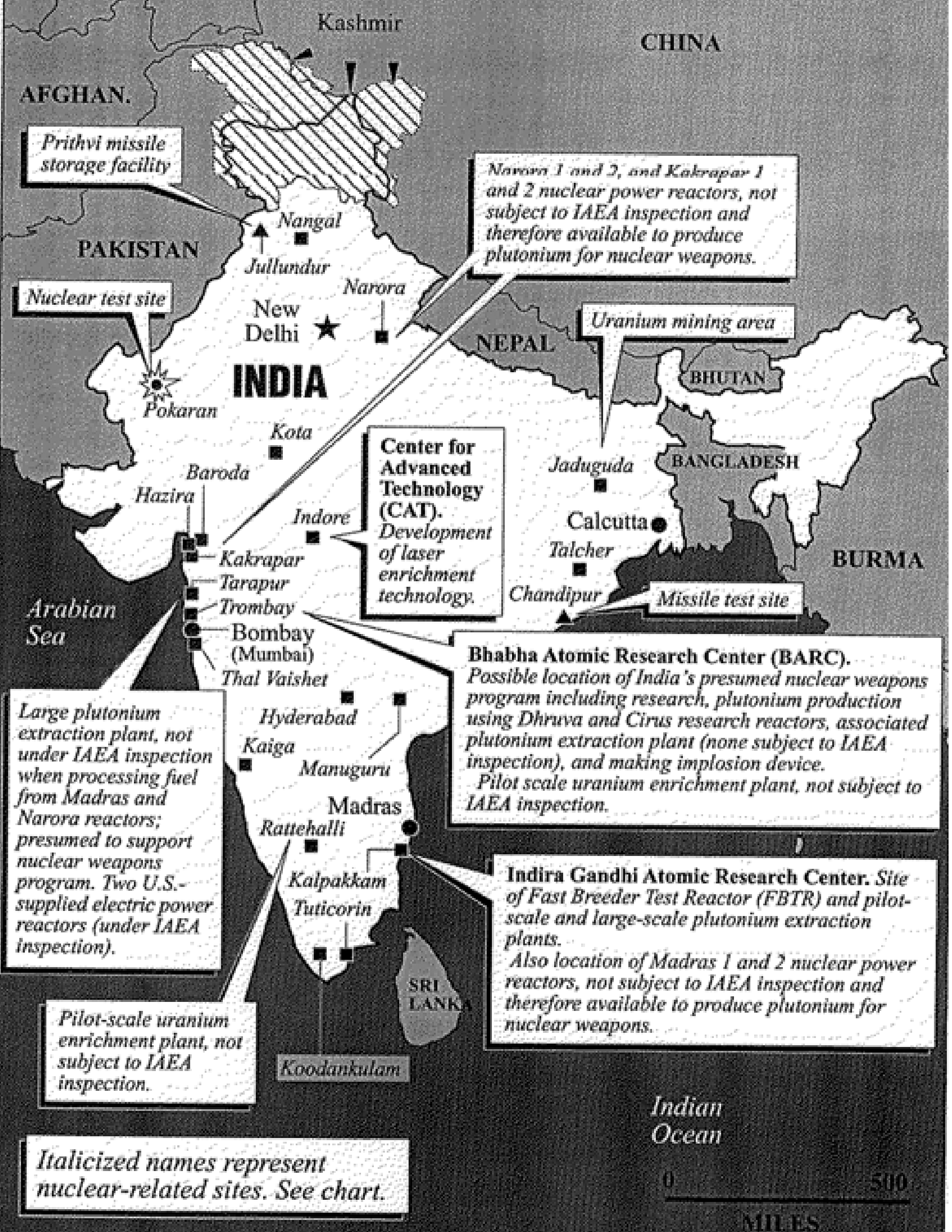
--1956: India completes negotiations to build 40 megawatt research reactor. United States supplies heavy water, used to control nuclear fission.
--1958: India begins designing and acquiring equipment for its Trombay plutonium reprocessing facility
--1959: U.S. trains Indian scientists in reprocessing and handling plutonium.
--1963: Two 210-megawatt boiling-water reactors are ordered for the Tarapur Atomic Power Station from General Electric. United States and India agree plutonium from India's reactors will not be used for research for atomic weapons or for military purposes.
--1964: First plutonium reprocessing plant operates at Trombay.
--1968: Non-Proliferation Treaty completed. India refuses to sign.
--1969: France agrees to help India develop breeder reactors.
--1974: India tests a device of up to 15 kilotons and calls the test a “peaceful nuclear explosion”. The United States allows continued supply of nuclear fuel, but later cuts it off.
--1998: India conducts 5 underground nuclear tests, declares itself a nuclear state

1-30 kT underground test series
SHAKTI



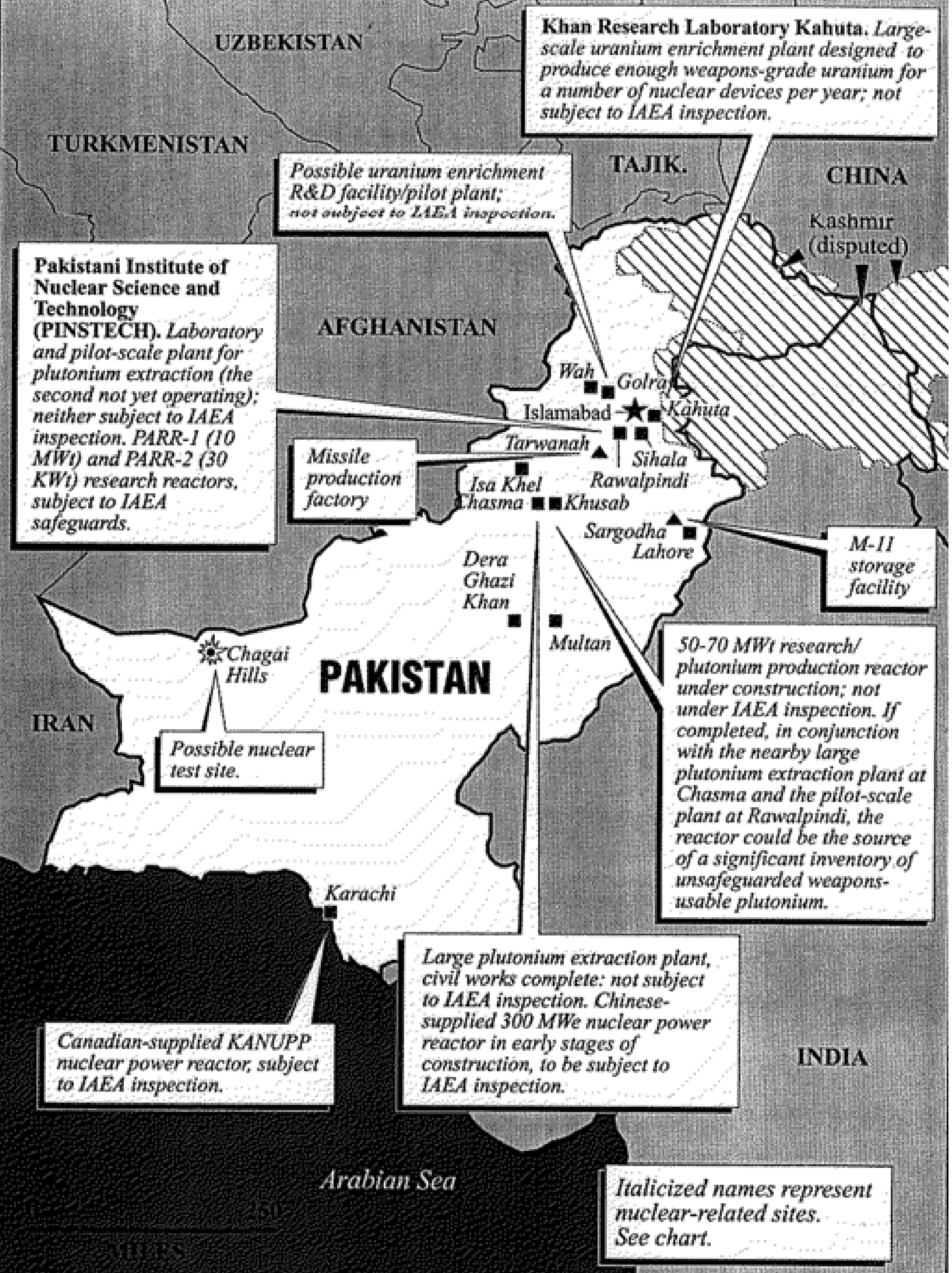
Several sub-kiloton test explosions

2005 Nuclear Research and Test Sites in India

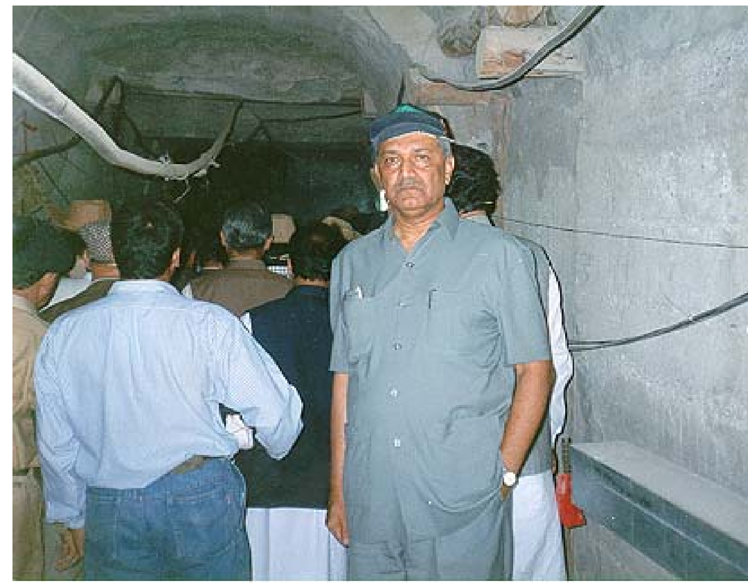


Pakistan

--1972: After third war with India, Pakistan decides to start nuclear weapons program to match India's developing capability. Canada supplies reactor for the Karachi Nuclear Power Plant, heavy water and heavy-water production facility.
--1974: Western suppliers embargo nuclear exports to Pakistan after India's first test of a nuclear device.
--1976: Canada stops supplying nuclear fuel for Karachi.
--1977: United States halts economic aid over Pakistan's nuclear-weapons program.
--1978: France cancels deal to supply plutonium reprocessing plant at Chasma.
--1983: China reportedly supplies Pakistan with bomb design.
--1987: Pakistan acquires tritium purification & production facility from West Germany.
--1989: A 27-kilowatt research reactor is built with Chinese help.
--1990: Fearing new war with India, Pakistan makes cores for several nuclear weapons.
--1991: Pakistan puts ceiling on size of its weapons-grade uranium stockpile. Agreement with India, prohibiting the attack of each other's nuclear installations.
--1993: Claims of 14,000 uranium-enrichment centrifuges installed in Pakistan. German customs officials seize about 1,000 gas centrifuges bound for Pakistan.
--1996: Pakistan buys 5,000 ring magnets from China to be used in gas centrifuges for uranium enrichment.
--1998: Reacting to fresh nuclear testing by India, Pakistan conducts its own atomic explosions.

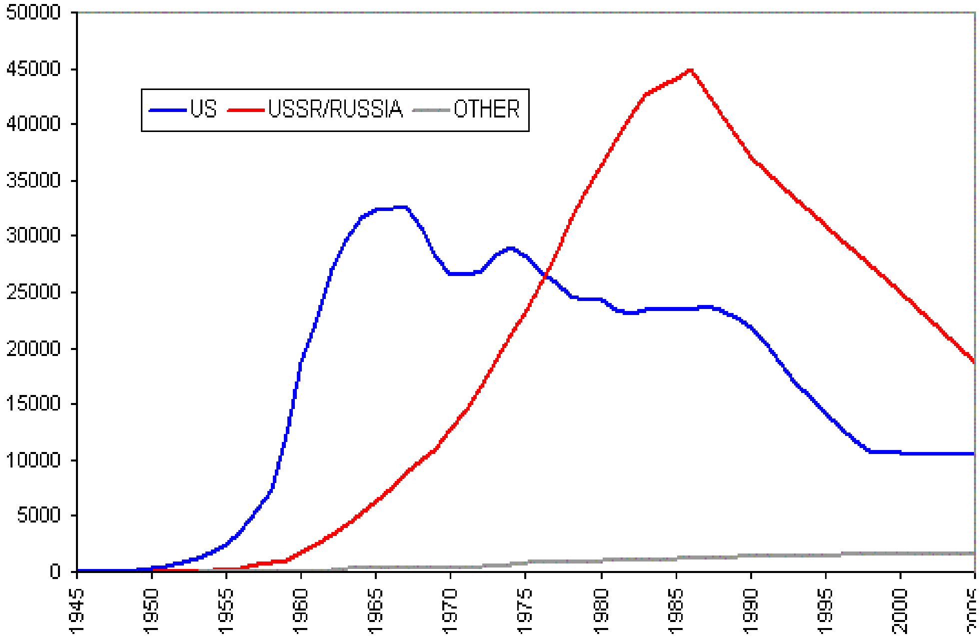


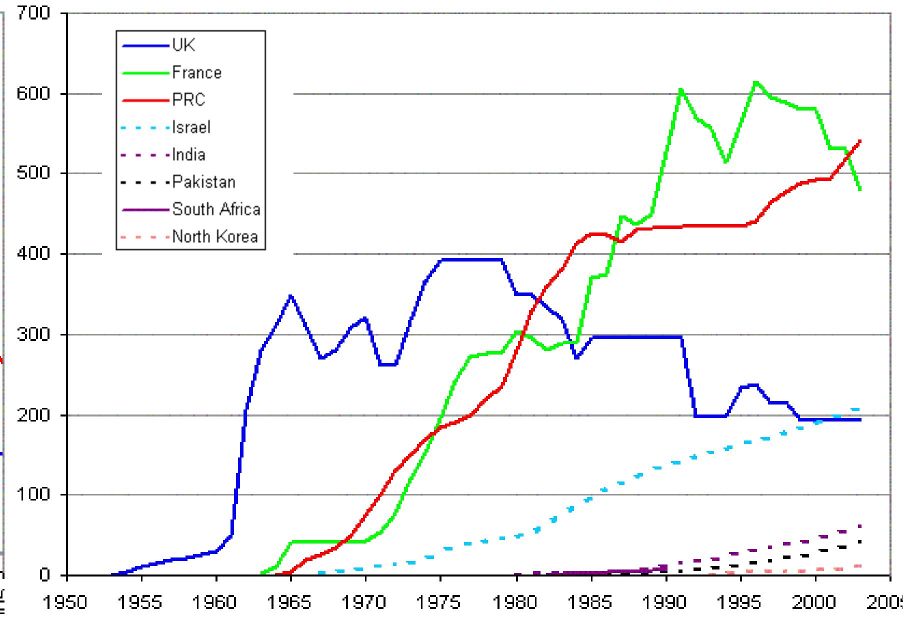
2005 Nuclear Research and Test Sites in Pakistan



Dr. Abdul Qadeer Khan, proclaimed as the "Father of Pakistan's atomic bomb," stands in the access tunnel inside the Chagai Hills nuclear test site before Pakistan's 28 May 1998 underground nuclear test.

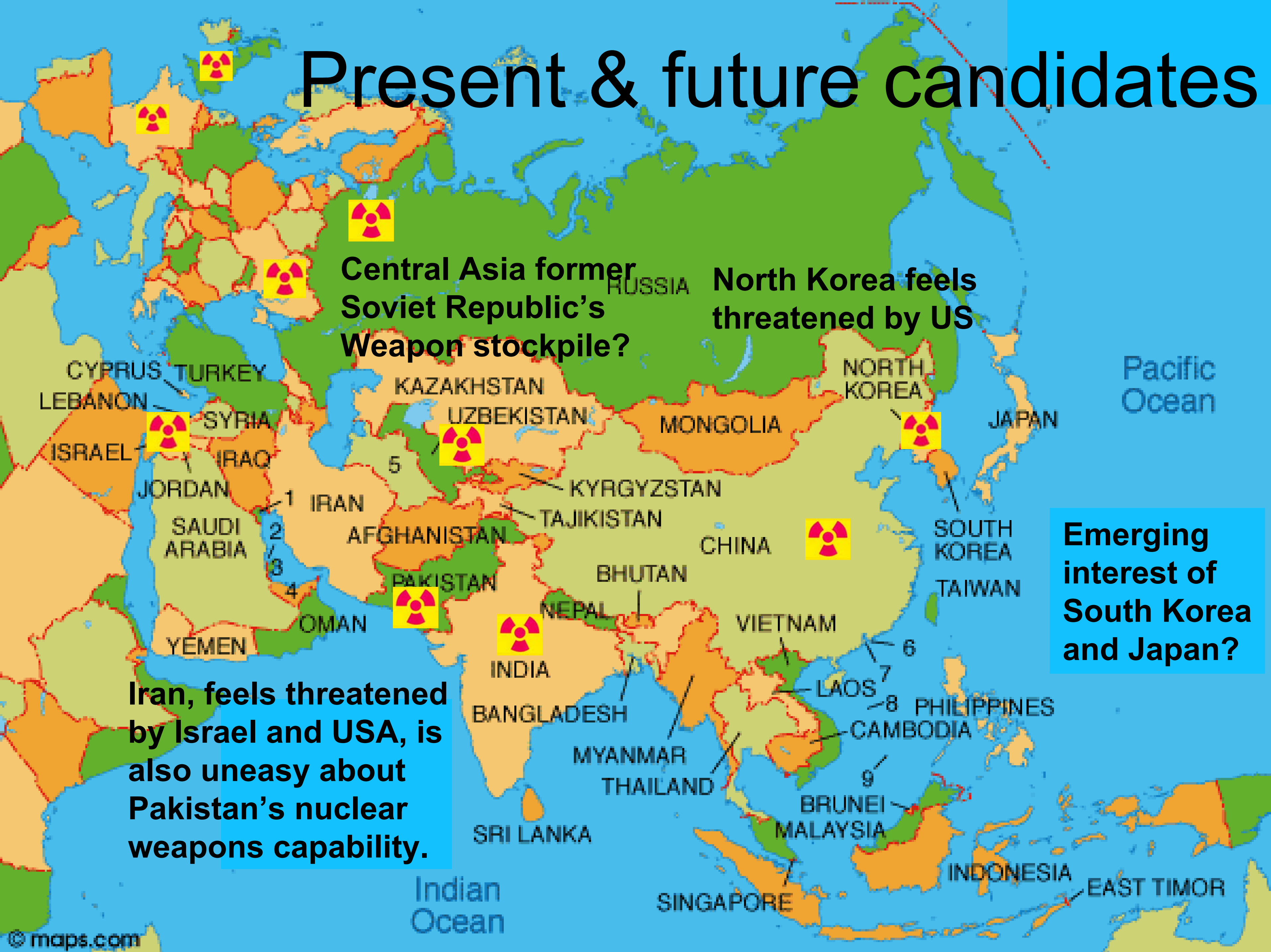
Nuclear Stockpiles





Stockpile on nuclear warhead as a function of year. US and Russia still maintain an nuclear arsenal that is one of magnitude (10 times) larger than the accumulated arsenal of the smaller nuclear powers.

Present & future candidates



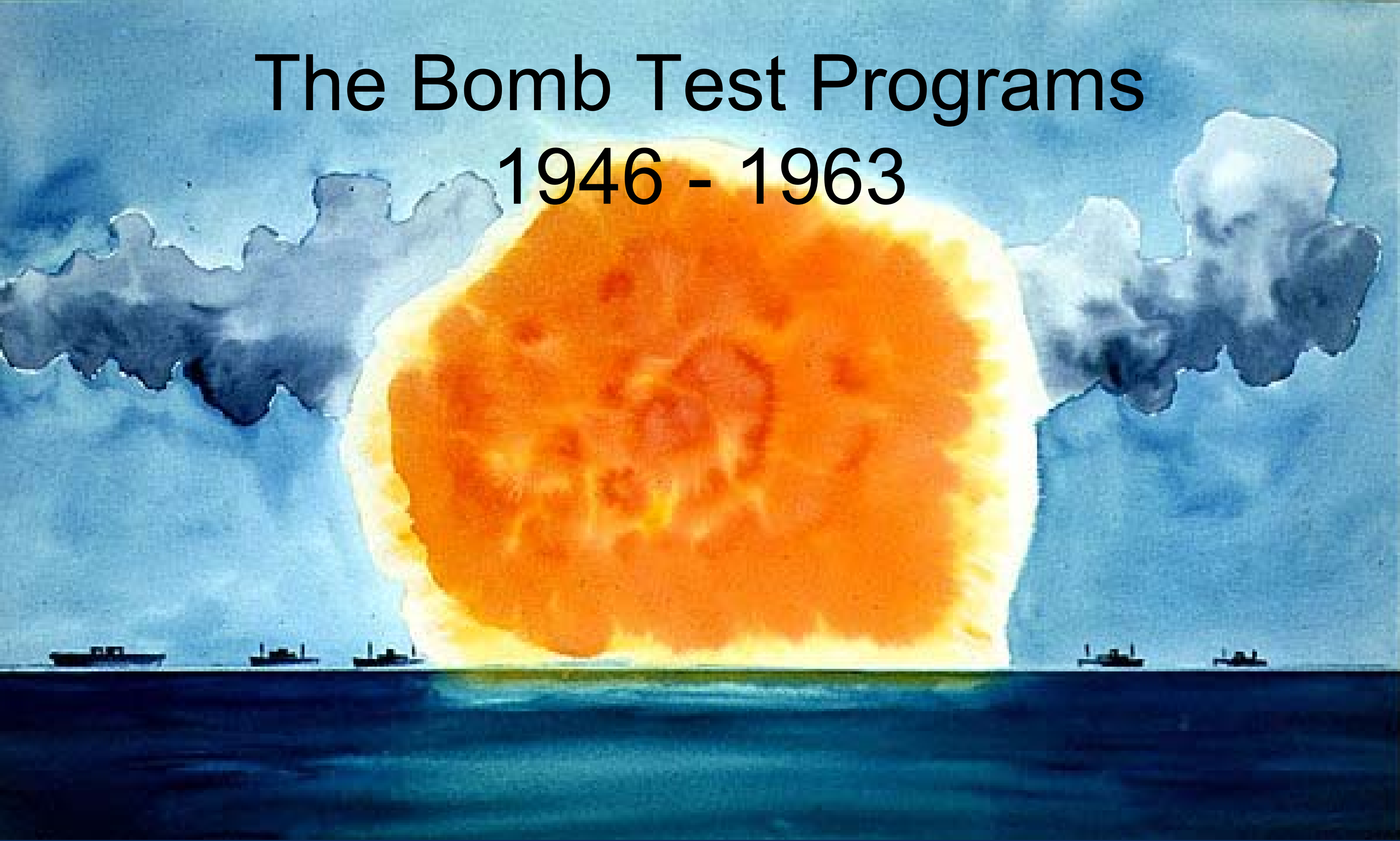
Central Asia former Soviet Republic's Weapon stockpile?

North Korea feels threatened by US

Emerging interest of South Korea and Japan?

Iran, feels threatened by Israel and USA, is also uneasy about Pakistan's nuclear weapons capability.

The Bomb Test Programs
1946 - 1963



Between 16 July 1945 and 23 September 1992 the United States of America conducted (by official count) 1054 nuclear tests, and two nuclear attacks. What are the reasons and results?

Art work by Grant Powell

List of US atmospheric Bomb tests

Operation	Year	Location	#
Crossroads	1946	Bikini Atoll	2
Sandstone	1948	Enewetak Atoll	3
Ranger	1951	Nevada Test Site	5
Greenhouse	1951	Enewetak Atoll	4
Buster-Jangle	1951	Nevada Test Site	7
Tumbler-Snapper	1951	Nevada Test Site	7
Ivy	1952	Enewetak Atoll	2
Upshot-Knothole	1953	Nevada Test Site	11
Castle	1954	Bikini Atoll Enewetak Atoll	6
Teapot	1955	Nevada Test Site	14
Wigwam	1955	Pacific Ocean	1

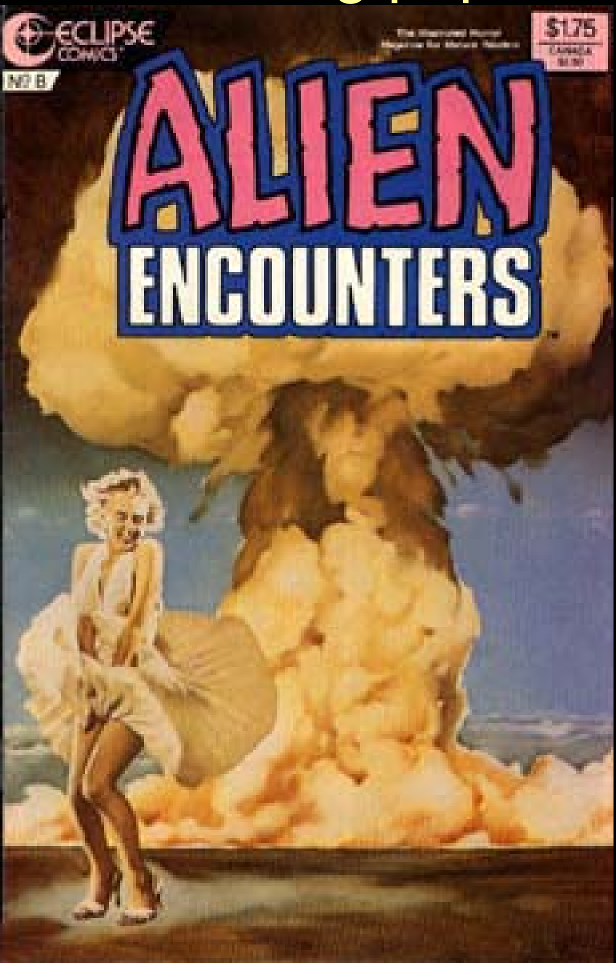
Pacific Atolls and Nevada desert areas

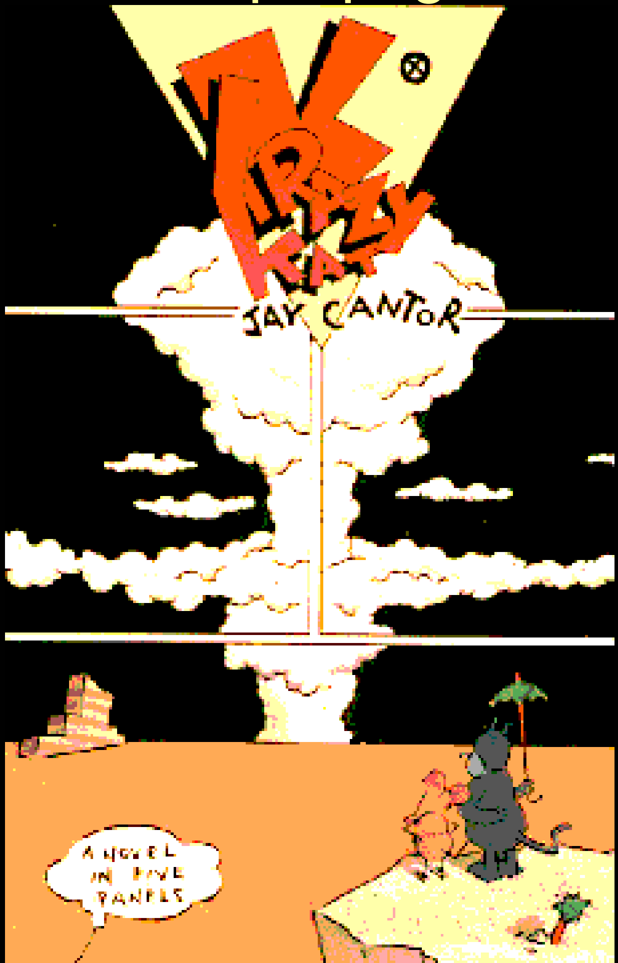
Project 56	1955	Nevada Test Site	4
Redwing	1956	Bikini Atoll Enewetak Atoll	17
Plumbbob	1957	Nevada Test Site	30
Project 58	1957	Nevada Test Site	2
Project 58 A	1958	Nevada Test Site	2
Hardtack I	1958	Bikini Atoll Enewetak Atoll Johnston Island	35
Argus	1958	South Atlantic	3
Hardtack II	1958	Nevada Test Site	37
Nougat	1961- 1962	Nevada Test Site	32
Dominic (with Fishbowl)	1962	Christmas Island Johnston Island Central Pacific	36
Storax (with Sunbeam and Roller Coaster)	1962- 1963	Nevada Test Site Nellis Air Force Range	56

316 tests until October 10, 1963; Limited Nuclear Test Ban Treaty

Preparation of Population

Test program needed psychological preparation of population
down-playing internal impact while up-playing external enemy
familiarizing population and society through media & propaganda

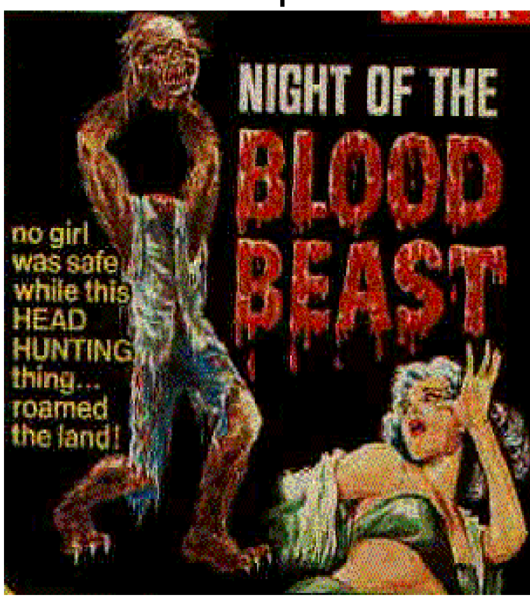





LAS VEGAS
5 ATOM TESTS
IN 11 DAYS
Pathe News
EXCLUSIVE

Play-Down of Dangers

- Presenting Nukes just as “bigger conventional” weapons
- Suggesting a “Communist take over” as bigger evil
- Belittling the threat and dangers of radiation exposure
- Declaring potential damage as manageable.
- Rapid Growth of “Fear Industry”!
  In movies, shelters,
  and protection devices



No way in stopping Hollywood!

Reporter Burchett wrote: "In Hiroshima, thirty days after the first atomic bomb destroyed the city and shook the world, people are still dying, mysteriously and horribly—people who were uninjured in the cataclysm from an unknown something which I can only describe as the atomic plague.“

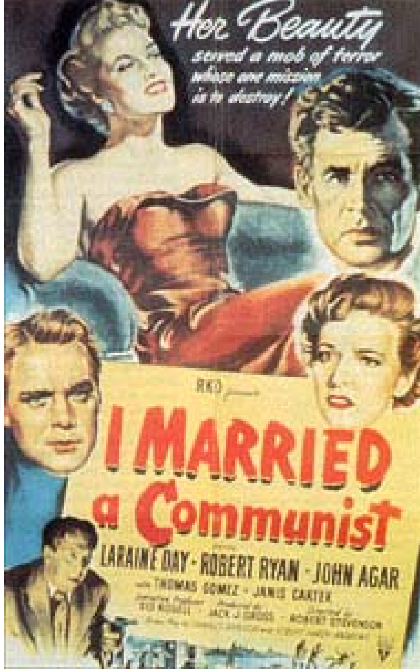
He continued, tapping out the words that still haunt to this day: "Hiroshima does not look like a bombed city. It looks as if a monster steamroller has passed over it and squashed it out of existence.“

Burchett's article, headlined THE ATOMIC PLAGUE, was published on September 5, 1945 in the *London Daily Express*. The story caused a worldwide sensation, and was a public relations fiasco for the U.S. military. The official U.S. narrative of the atomic bombings downplayed civilian casualties and categorically dismissed as "Japanese propaganda" reports of the deadly lingering effects of radiation.

Just big conventional weapons

The Commies are coming, the Commies are coming!

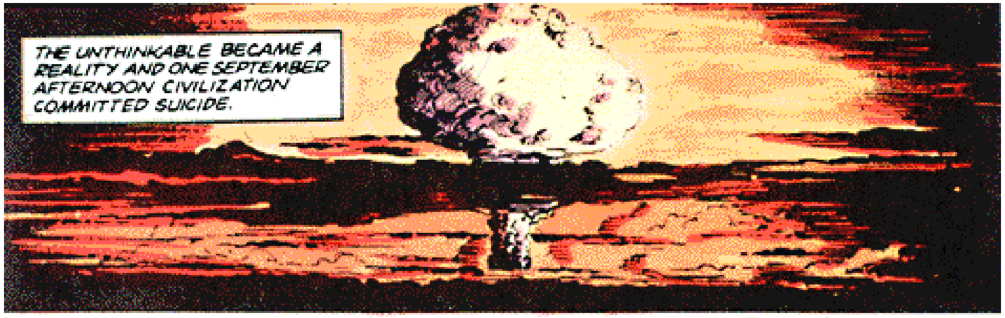
The Red Nightmare:
Federally funded propaganda film
The tale of an ordinary American town and its life as a Communist satellite, with everyone becoming emotionless automations.

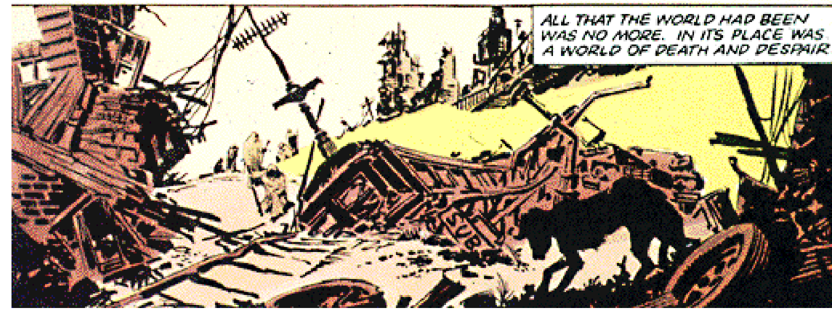


Invasion, USA is the key cold war 'scare' picture. Unlike pacifist weepies such as Arch Oboler's **Five**, this show depicts a Soviet Union so aggressive, Senator Joe McCarthy wouldn't recognize it.

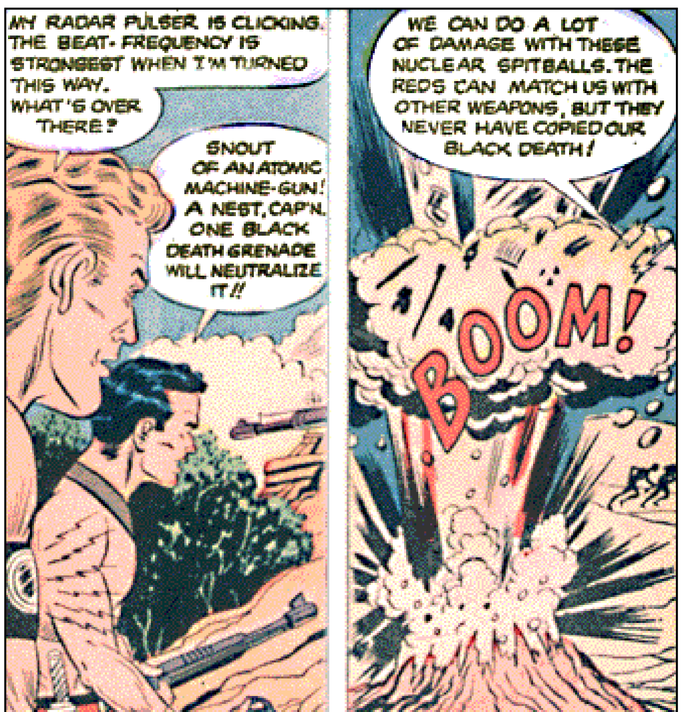
The Fear Factor

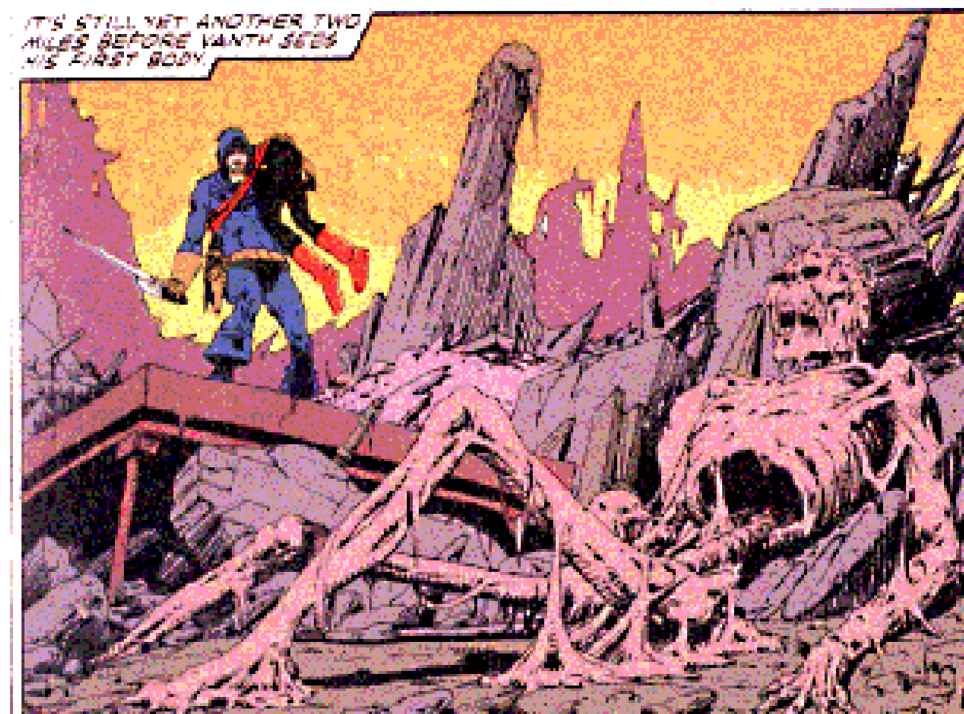
Comic Book Industry



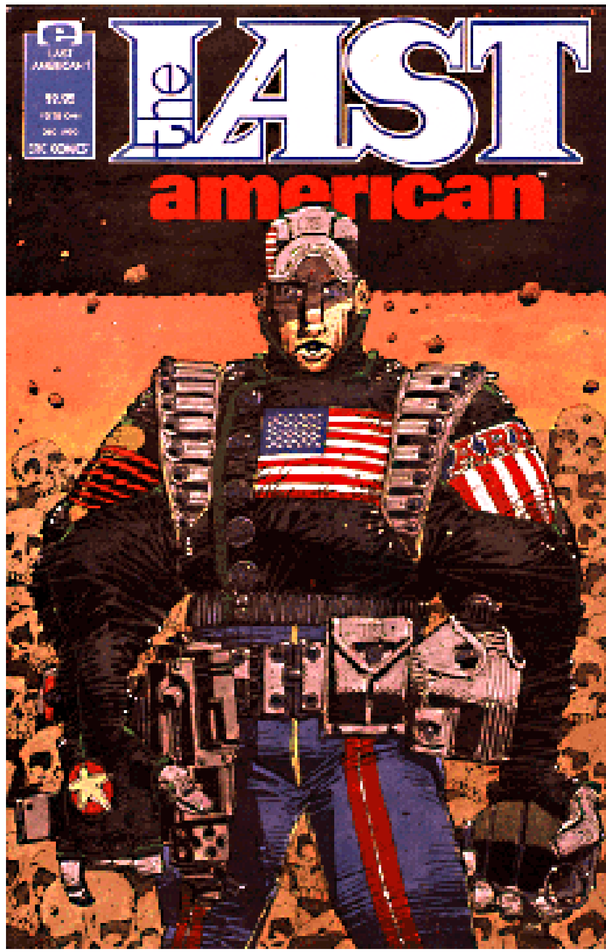


Presenting violence and horror with
“the good guys” beating “the bad guys”



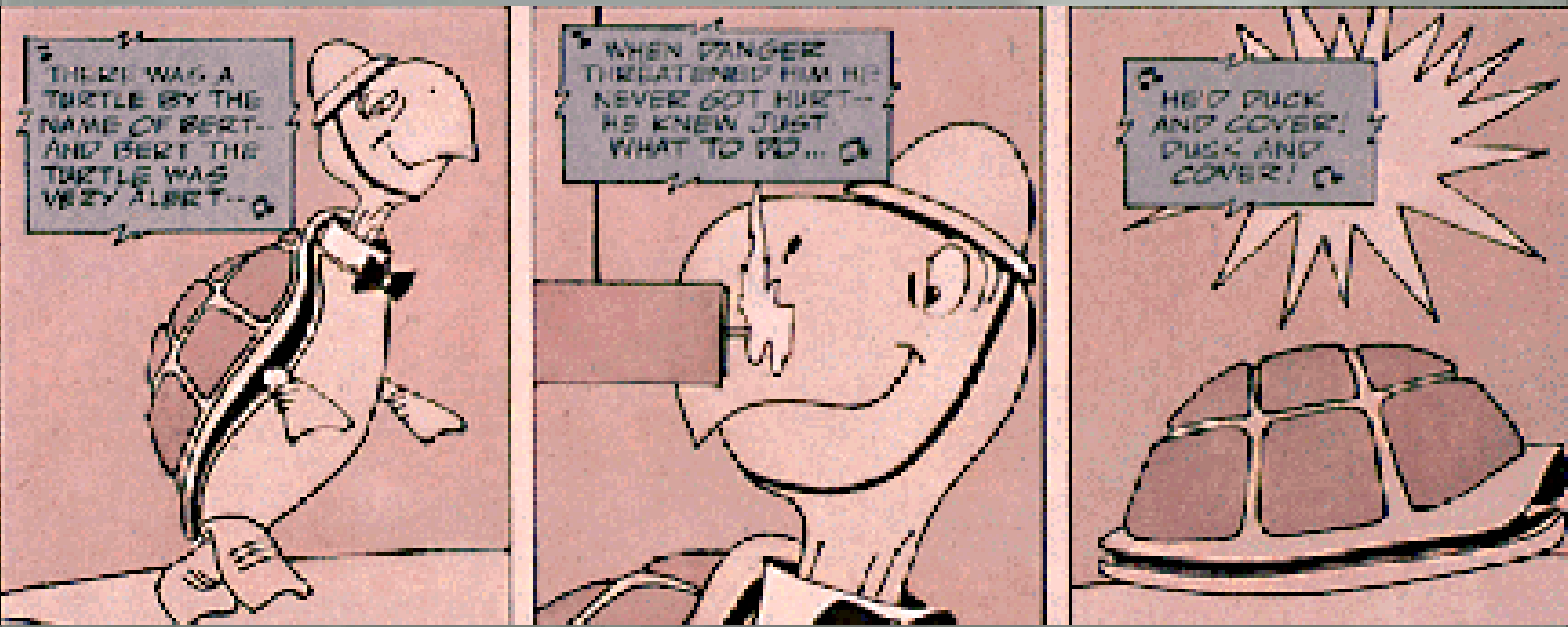


The American Hero at the End of Times



No doubt or criticism was voiced in media, film, and popular literature towards arms race, weapons development and testing!

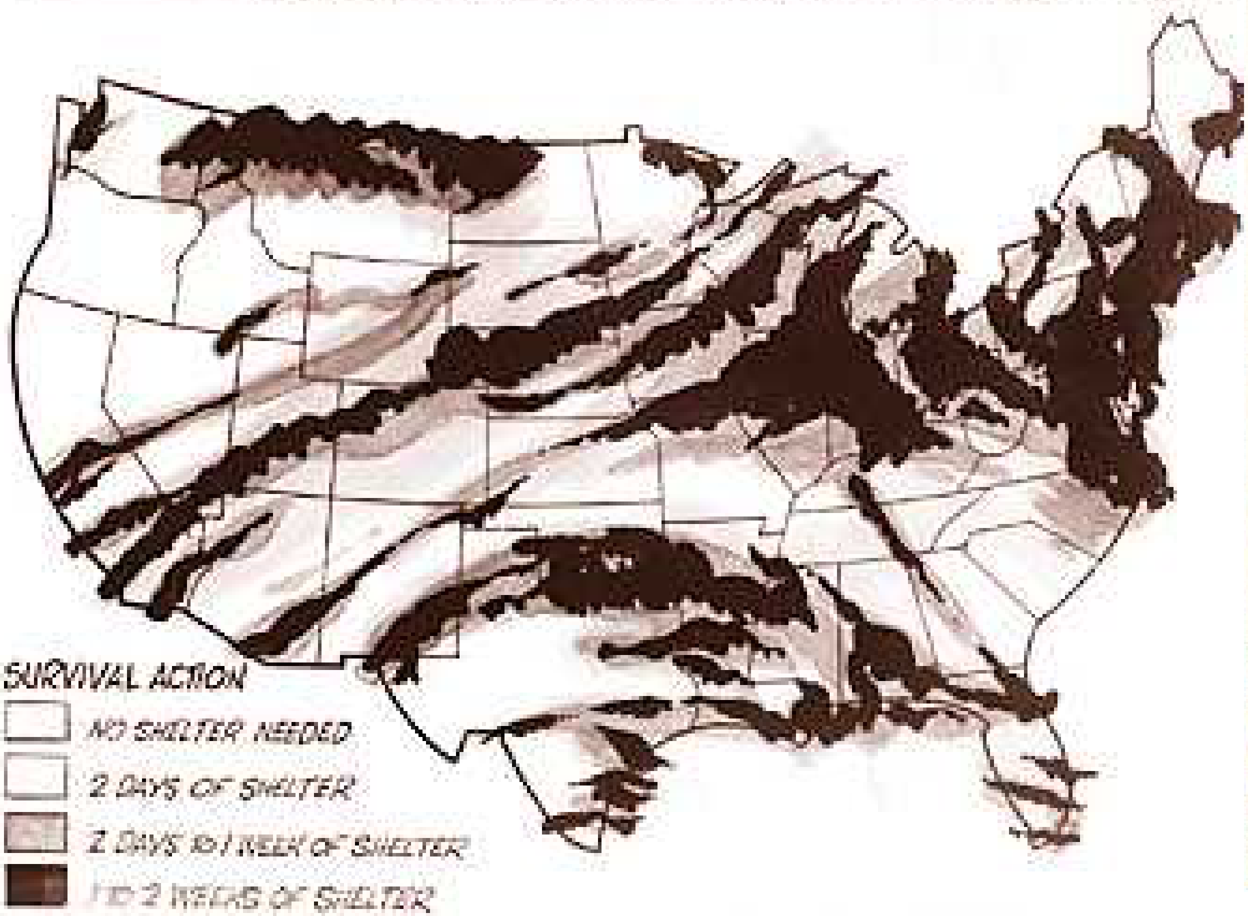
Duck and Cover



Training to be prepared and to accept the “unavoidable”!

The public warning system

Fallout on a Spring Day From an Assumed Attack on a Wide Range of Targets



Public Urged To Report On Siren Test Tomorrow

All Civil Defense wardens will make telephone reports to the Pittsfield control center following tomorrow noon's three-minute test of the city's siren system, starting at 12:15.

Chief Warden Volney M. Sedgwick said the wardens are to tell how well they heard the red alert, sounded by the 15 sirens and four factory whistles.

CD Director William H. Cooney urged everyone in Pittsfield to fill out the coupon appearing with this story, so that effectiveness of the sirens can be accurately determined. It is equally important to send in the coupon if the sirens are not heard at all, he said.

Business as Usual

Director Cooney reminded the public that business will go on as usual throughout the city. There will be no need to take cover as in past alerts, he said.

This will be the first time in four weeks that the every Saturday 12:15 alert will be sounded. Four new sirens have been installed in the meantime, and six have been relocated.

CD Siren Audibility Report

During the siren test on Saturday the audibility at the address below was: Good ☐ Fair ☐ None ☐

I was: Inside ☐ Outside ☐

Name ....

Address ....

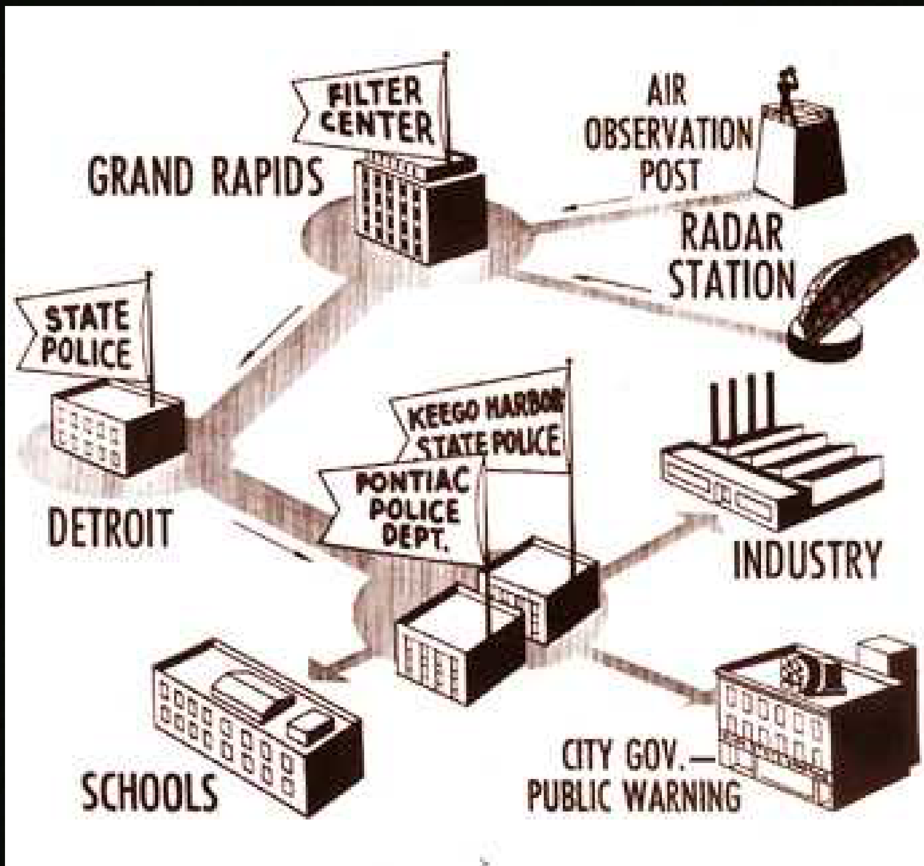
Please fill in and mail to:

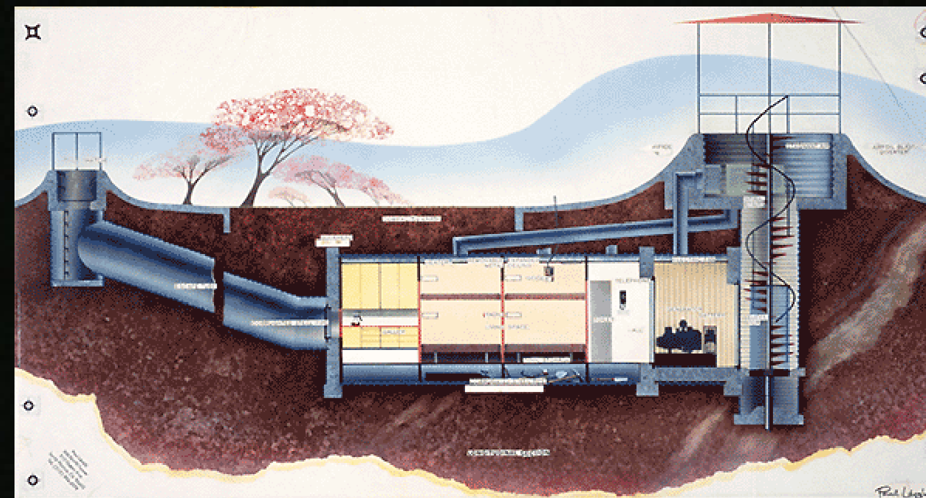
Civil Defense
City Hall Annex
Pittsfield

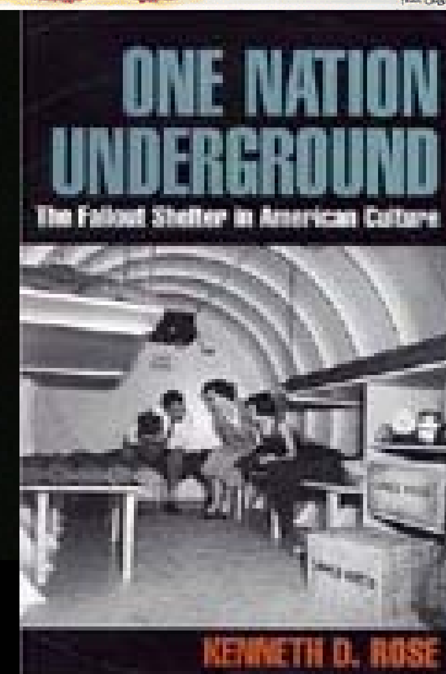
1955

Personal Preparation

Preparation and Shelter







Public shelter and warning system was installed
Purchasing private “atomic bunker” system became big business. Business based on fear and false information.

Shelter Guide

By 1960, The Office of Civil and Defense Mobilization, estimated that a million families had constructed their own private bomb shelters. Shelters ranged in price from $1,795-$3,895, and of course many came in kits that make assembly much easier. Advertisements were found in magazines throughout the country. Many companies were capitalizing on Americans fear. Life Magazine in 1955, included a feature ad for a H-Bomb Hideaway, and the sale price was only $3000. Bob Rutske, a Michigan Sheriff at the time, remarked that "To build a home today without a shelter, would be like leaving out a bathroom twenty years ago." The number of shelters that were built in that era, show how well propaganda had penetrated the American mind.

RADIUS ENGINEERING INC.

Engineered Underground Shelters

Back in business?

CAT 25 Military Shelter	$186,400.00
Hatch Dome Class I	-------------
Food/Fuel Package	Included
Communications Package	Included
Solar charging option	$ 950.00
Manual Septic Pump/25 feet hose	Included
Air Blower (spare)	Included
45 AMP Battery Charger	Included
Product On Site Assembly, Installation, Delivery	Quoted

Total Order - NH has no sales tax

50% Down Payment - check or wire transfer only

Balance Due 10 days Prior to Shipping Payment by check or wire transfer

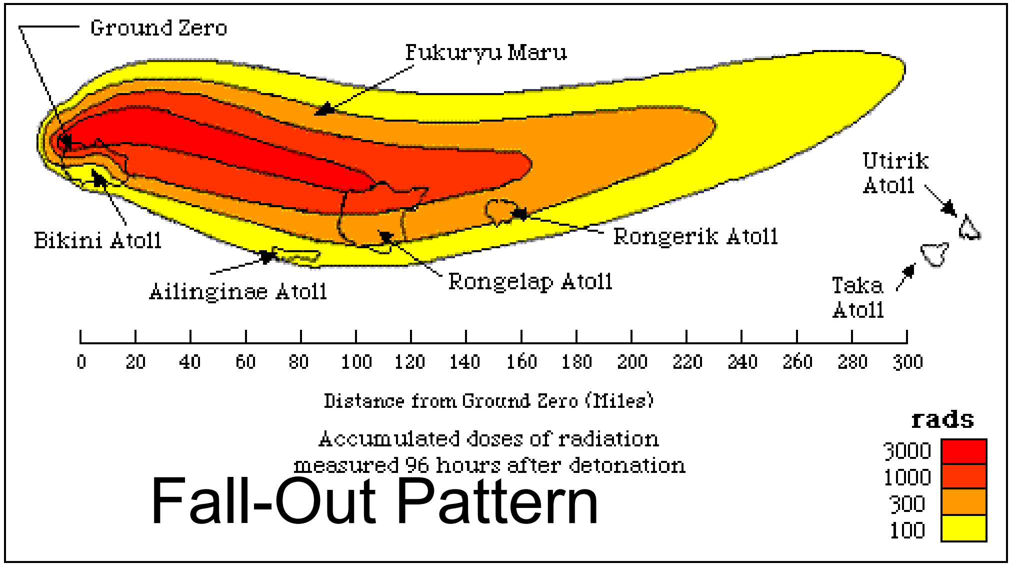
See Conditions Of Sale - Cancellation Fee is 20% of order.

But there were limits …

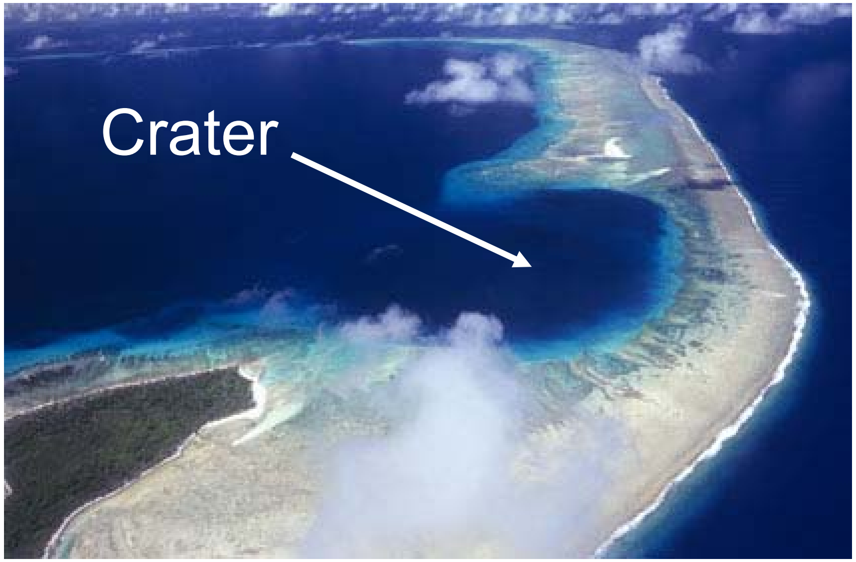
To realistic movies and or satire was suppressed or forbidden to avoid the generation of criticism and/or panic reactions.

Nukes as business motivator

March 1, 1954
Hydrogen Bomb test on **Bikini** Atoll; **Louis Réard**, thought his daring new swimsuit would have an impact comparable to the impact of the bomb.



Fall-Out Pattern



Nukes became normal part of everybody’s life

But accidents occurred and criticism grew slowly but surely!

The Nature of the Blast

Blast—40-60% of total energy
Thermal radiation—30-50% of total energy
Ionizing radiation—5% of total energy
Residual radiation (fallout)—5-10% of total energy

The results of the weapons test programs

- Efficiency of explosion
- Kind and shape of blasts
- Blast effects, range & damage
- Thermal effects
- Radiation effects

Classifications of blasts

- Surface Blast:
  fireball in touch with surface
  vaporization of surface structures through blast
  and firestorm, immediate radioactive fallout
- High Altitude Air Blast:
  fireball > 100,000 ft (>3000m)
  interrupts satellite based communication
  through electromagnetic pulse (EMP)
- Low Altitude Air Blast:
  fireball < 100,000 ft (without touching ground)
  generates shock waves, pressure difference
  artificial for large areal damage, sea battle
- Subsurface Blast:
  Underwater burst
  generates surge

Surface Blast – the fireball

Stokes
August 1957
1500 Foot Balloon
19 kt

Central temperature: ~10,000,000 K
Immediate vaporization of material!
Central pressure: ~33000 atm

- Radiation release & absorption in surrounding matter generates red-glow intense luminosity.
- Expansion of fireball through internal pressure
- Fireball rises like hot air balloon

Fireball expansion

Pressure evolution
within the fireball:

$$p \cdot V \propto T; \quad V \approx const$$

$$T_1 \approx 300\,K,\ p_1 \approx 1\,atm,\ T_2 \approx 1 \cdot 10^6\ K$$

$$\frac{p_2}{p_1} \approx \frac{T_2}{T_1} \approx \frac{1{,}000{,}000}{300} \approx 3300\ atm = 50{,}000\,psi$$

Sedov Taylor approximation (valid of first 0.1s) allowed Russians to estimate the power of the Trinity bomb from the expansion time conditions

$$E = K \cdot \rho \cdot r^5 \cdot t^{2/5} \quad K \approx 1,\ \rho_0 = 1kg/m^3$$

$$r \approx 950 \cdot (t)^{2/5}\ [m]$$

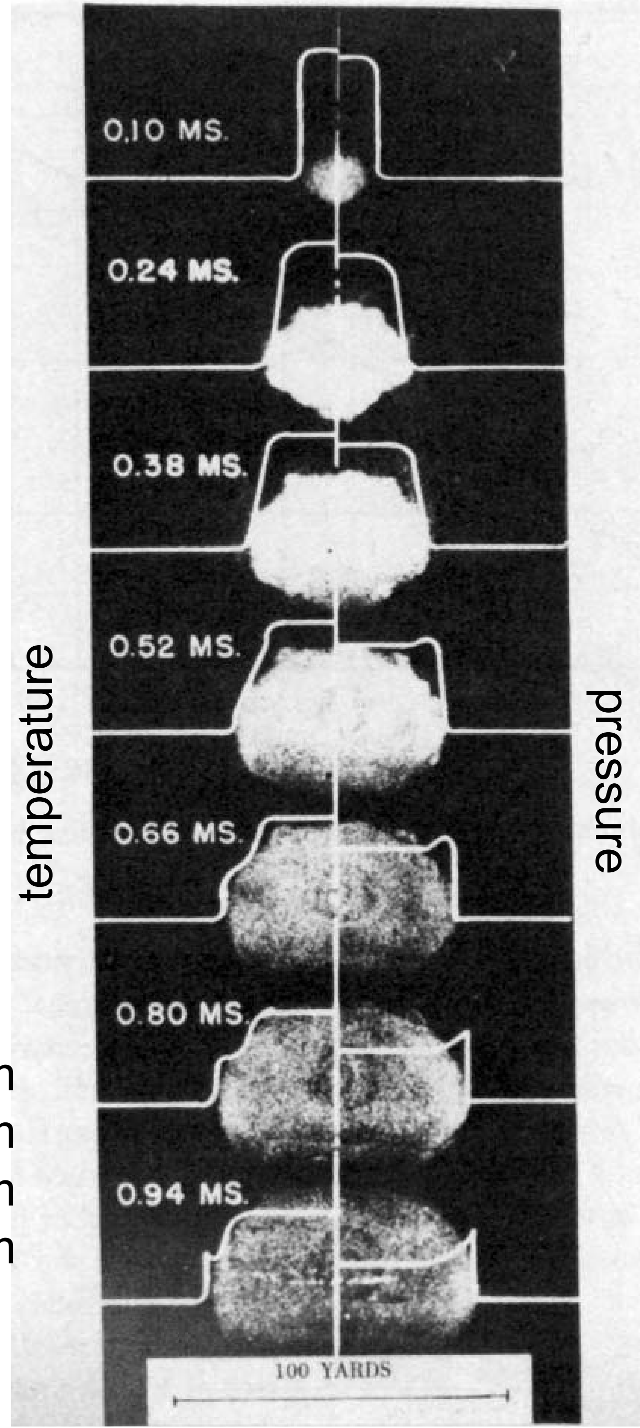
$$\rho \approx \rho_0 \cdot \frac{P}{P_0}$$

$$E \approx K \cdot \rho_0 \cdot \frac{P}{P_0} \cdot 7.74 \cdot 10^{14} \cdot t^{8/5} \approx 4.04 \cdot 10^{13}\,J \quad (t = 1ms)$$

$$1\,kt\,TNT = 4.18 \cdot 10^{12}\,J$$

$$E \approx 10\,kt\,TNT$$

t	r
0.1 ms	24 m
0.4 ms	42 m
0.7 ms	52 m
0.9 ms	60 m



Expansion speed

Initial expansion speed *v* (T≈1,000,000 K)

c_s is the speed of sound in the vaporized gas
γ is the specific heat ratio of the gas
R is the gas constant: 287 [J/kg K]; *T* is temperature [K]

$$v = \frac{2 \cdot c_s}{\gamma - 1} \quad c_s = \sqrt{\gamma \cdot R \cdot T} \approx 20\, km/s; \quad \gamma \approx 1.5$$ Fully ionized plasma

$$v = \frac{2 \cdot 20}{1.5 - 1} = 80\, km/s \approx 240{,}000\, ft/s$$

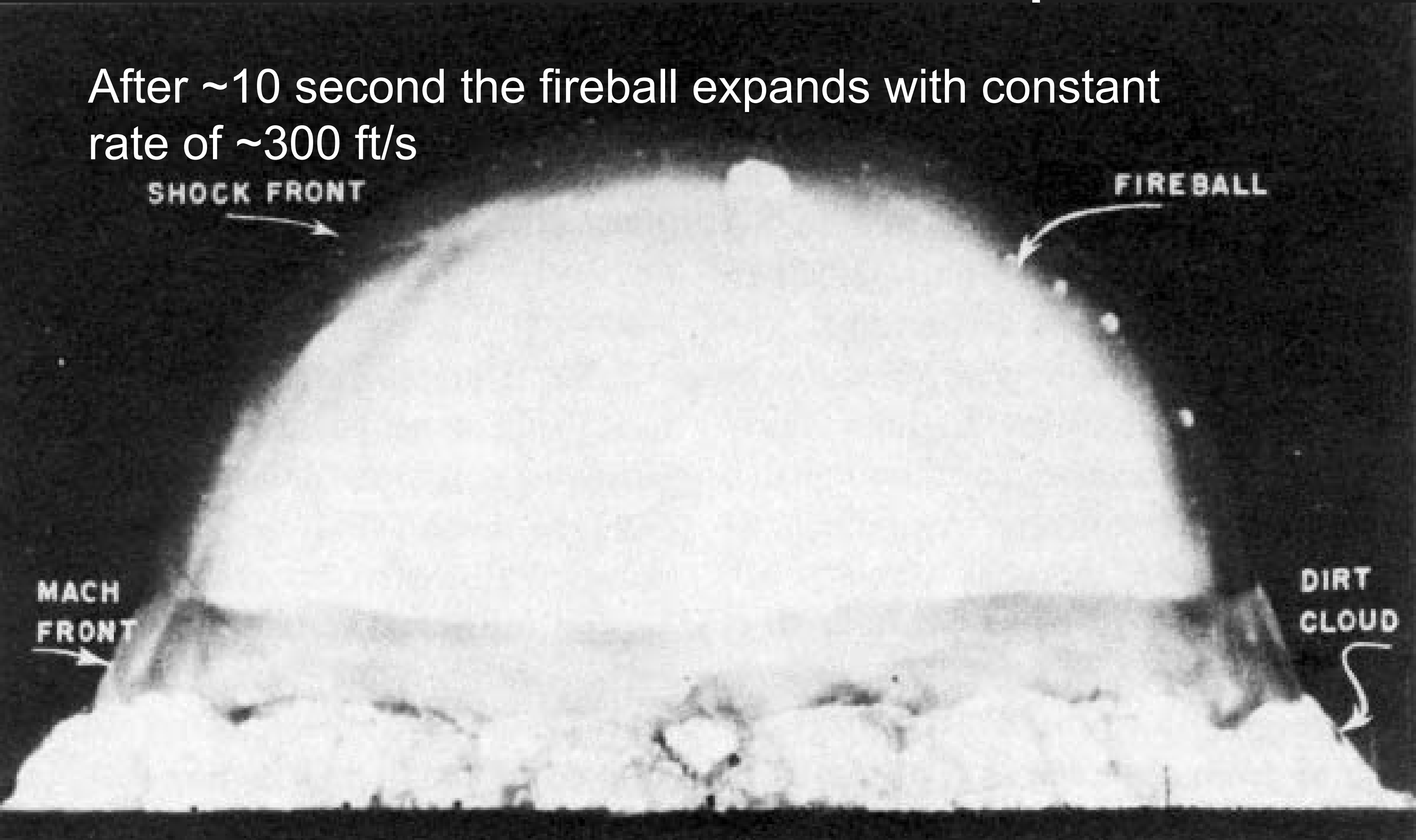
Cool-down to T≈3,000 after 15 ms due to radiation losses

$$v = \frac{2 \cdot c_s}{\gamma - 1} \quad c_s = \sqrt{\gamma \cdot R \cdot T} \approx 1\, km/s; \quad \gamma \approx 1.25$$ Ideal gas

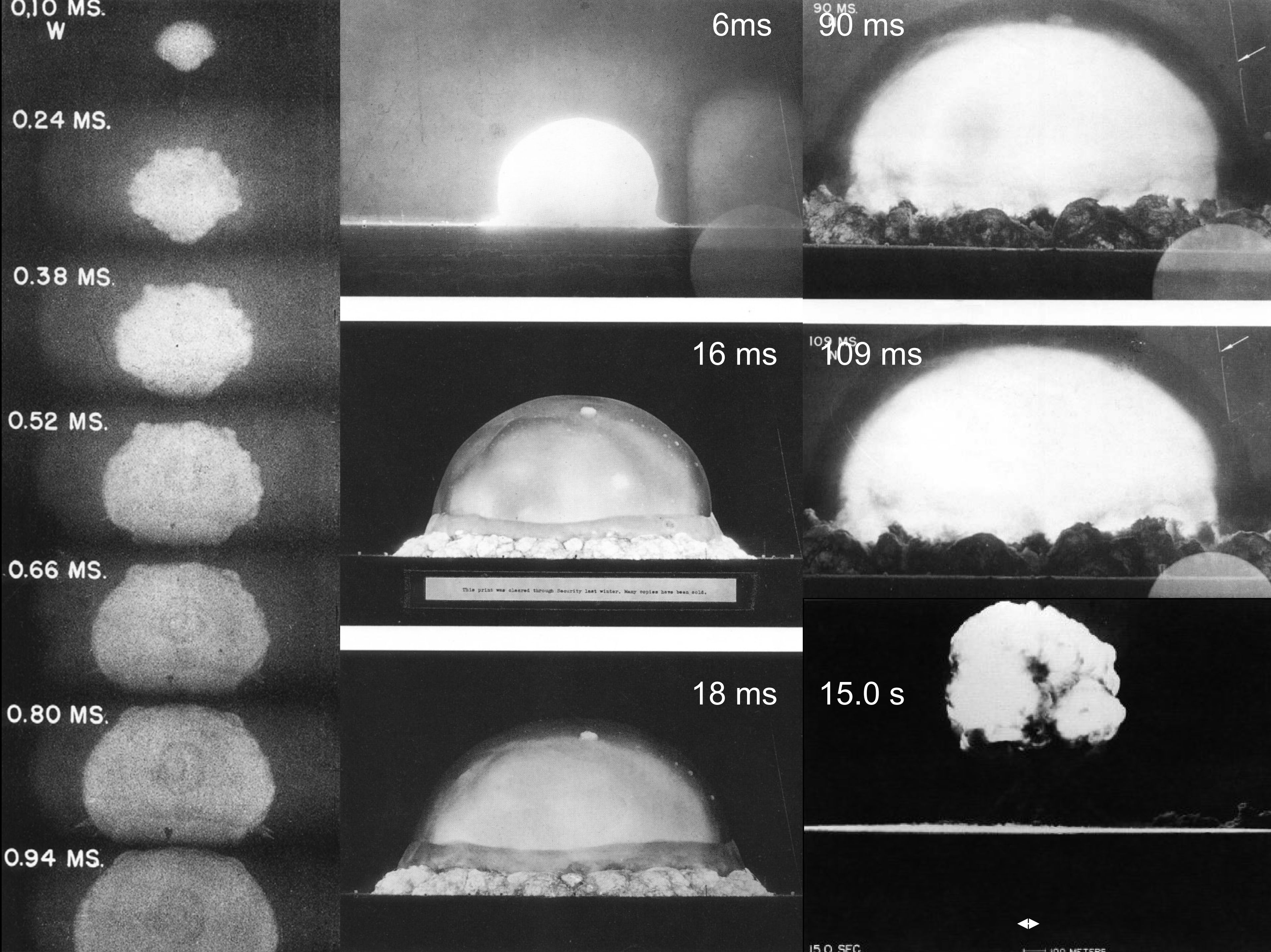
$$v = \frac{2 \cdot 1}{1.25 - 1} = 8\, km/s \approx 24{,}500\, ft/s$$

The shock front development

After ~10 second the fireball expands with constant rate of ~300 ft/s



After ~ 1minute fireball has cooled and radiation emission ceases!


0,10 MS.
W
0.24 MS.
0.38 MS.
0.52 MS.
0.66 MS.
0.80 MS.
0.94 MS.
6ms
16 ms
This print was cleared through Security last winter. Many copies have been sold.
18 ms
90 MS.
90 ms
109 ms
15.0 s

Analysis of Fire ball

Sedov-Taylor Blast analysis

$$R = \left(\frac{E}{K \cdot \rho_0} \right)^{1/5} \cdot t^{2/5}$$

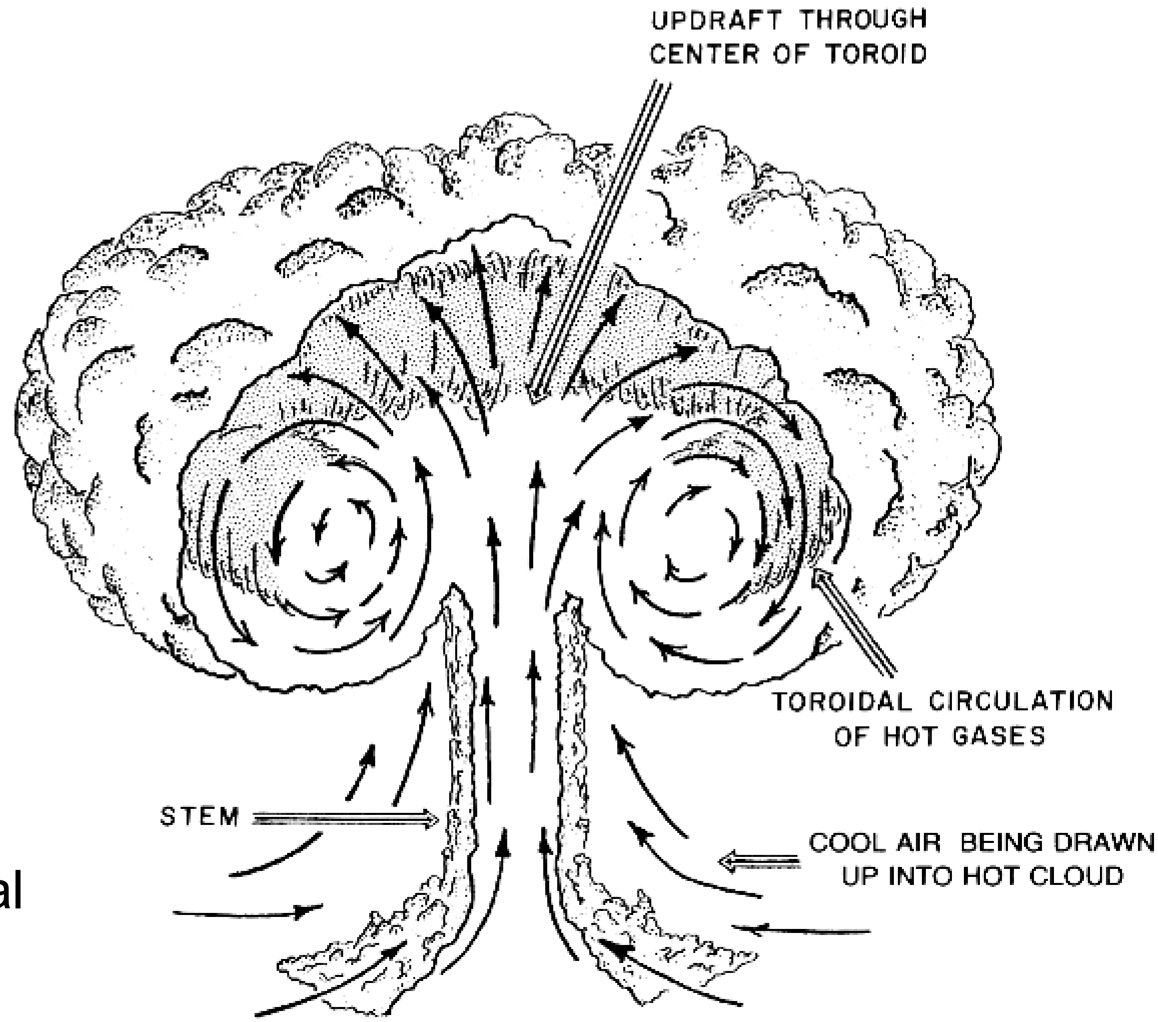
Valid as long as shock is super sonic: $K \approx 1$
Approximation allowed Russian scientists to estimate the power of US Trinity bomb.

Evolution of Mushroom cloud

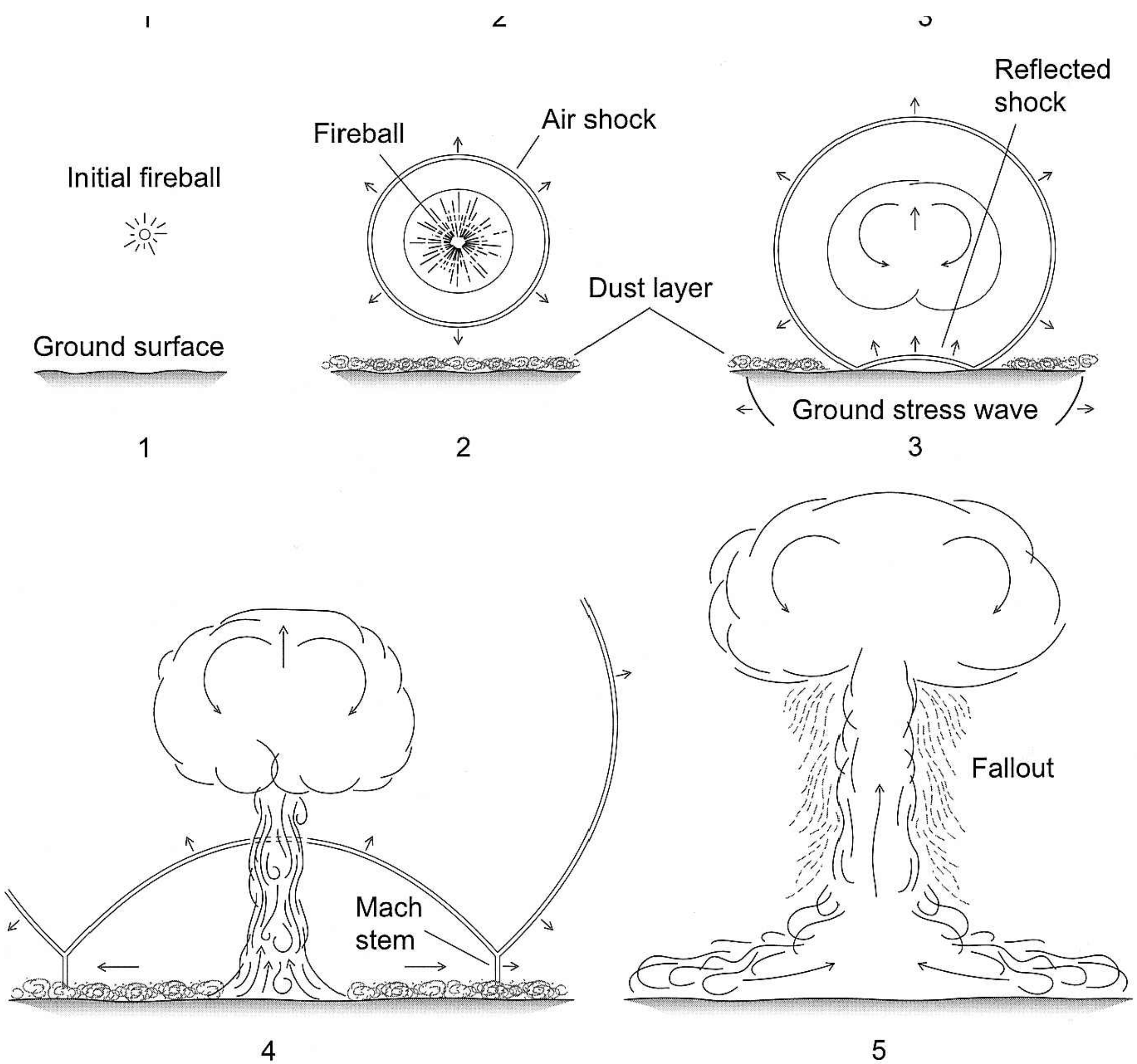
General Features – the mushroom

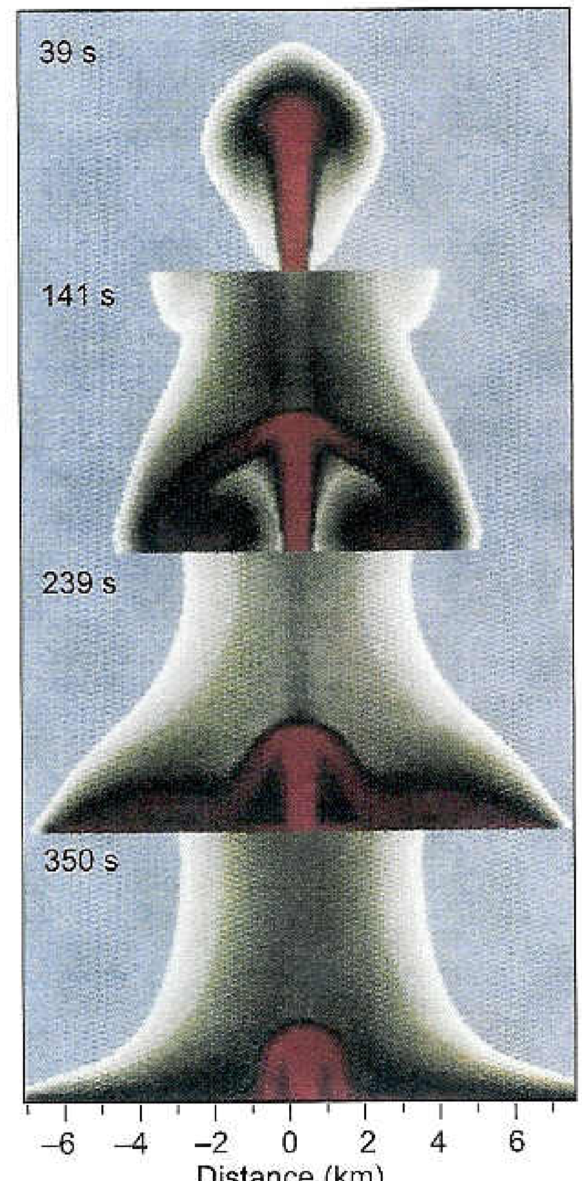
the emergence of the mushroom shape

- Absorption of cool air triggers fast toroidal circulation of hot gases and causes upward motion forming the stem and mushroom.
- Condensation of water changes red brownish color of cloud towards white!
- Strong upward wind Drags dirt and debris Into the cloud mixing with radioactive material
- Cloud rises in height with ~ 440 ft/s

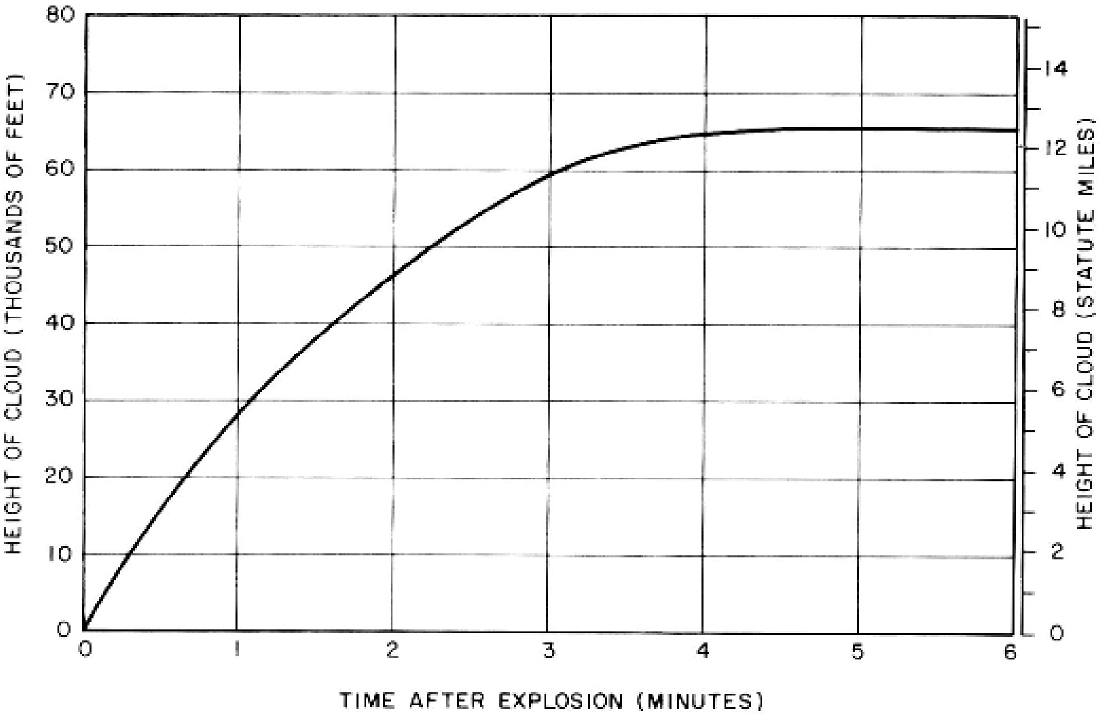


Model


Initial fireball
Ground surface
1
Fireball
Air shock
Dust layer
2
Reflected shock
Ground stress wave
3
Mach stem
4
Fallout
5


39 s
141 s
239 s
350 s
−6
−4
−2
0
2
4
6
Distance (km)


Dirt

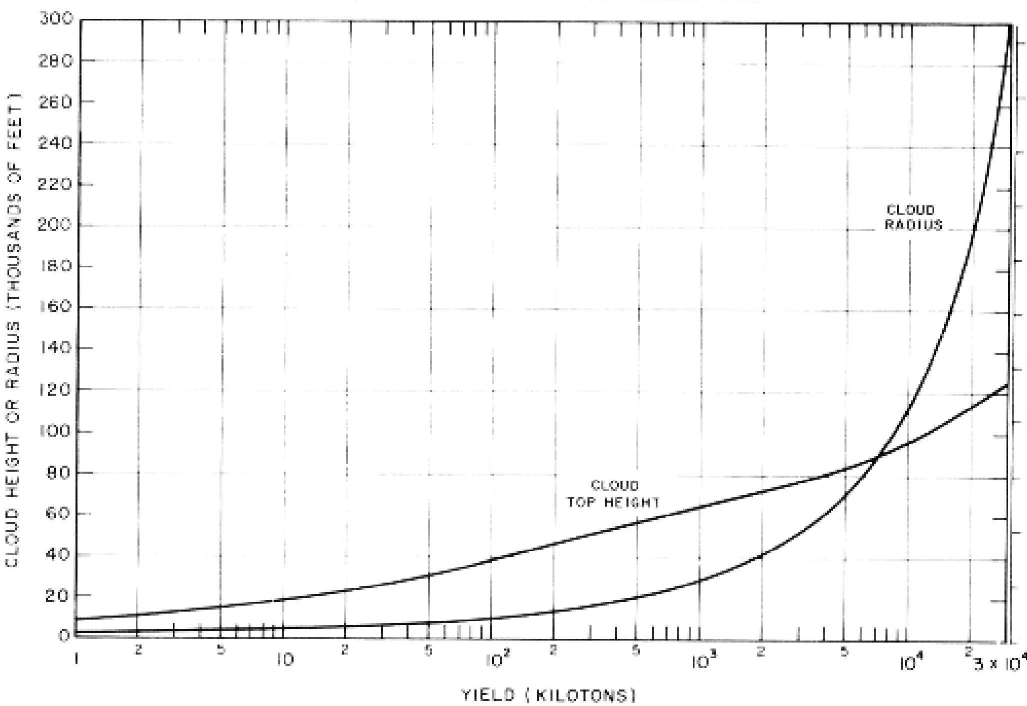


Cloud Altitude

Maximum altitude for cloud rise is reached after ~ 4min.

RATE OF RISE OF THE RADIOACTIVE CLOUD FROM a I-MEGATON AIRBURST

Height (miles)	Time (min)	Rate of Rise (mph)
2.0	0.3	330
3.0	40.7	270
4.0	61.1	220
5.0	102.5	140
6.0	123.8	27



Cloud height & cloud radius depend on the magnitude of the explosion, increase of both radius & height scales with explosion yield.

Chimney effect again!

$$v = 0.65 \cdot \sqrt{2g \cdot H \cdot \left(\frac{T_i - T_o}{T_i} \right)}$$

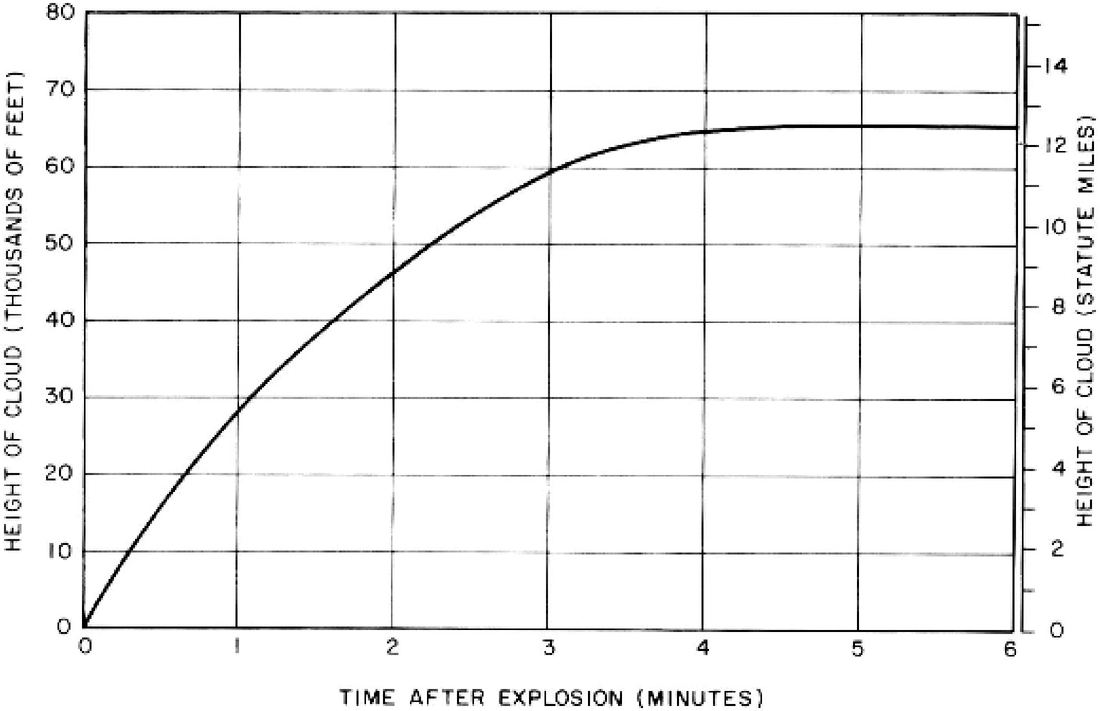
v=wind velocity in m/s
g=9.8 m/s^2 earth acceleration
H=height of heat column in [m]
T_o=outside temperature, K
T_i=inside temperature in K

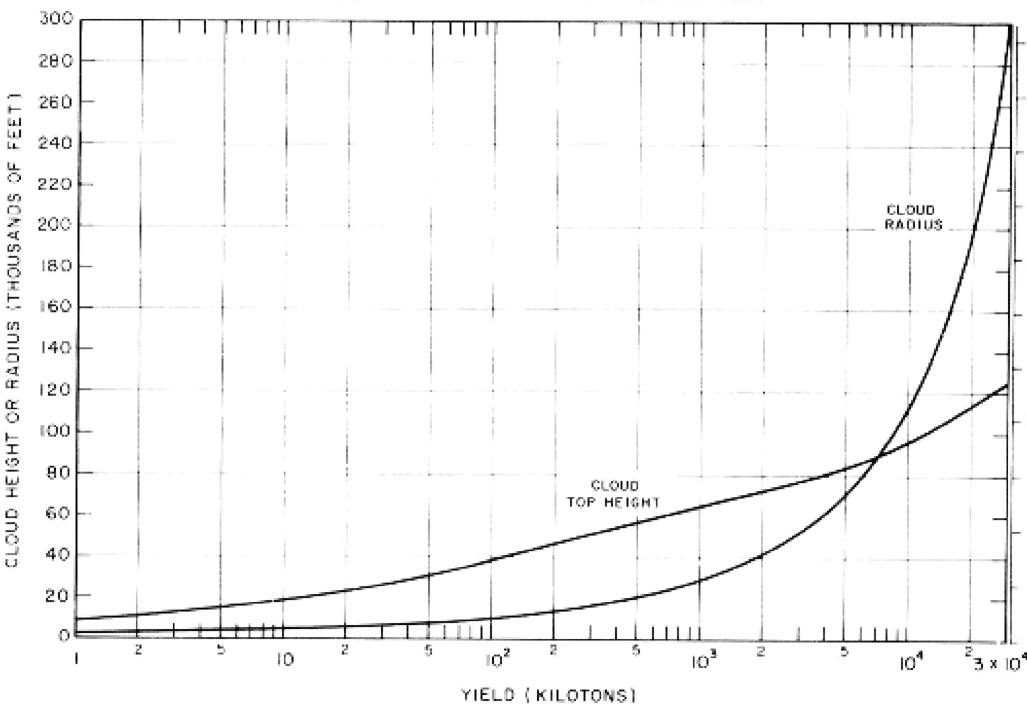
For typical firestorm:
H ≈ 10,000 m
T_i ≈ 1,000,000 K
T_o ≈ 300 K

⇨ v ≈ 288m/s = 647 miles/h

Hurricane speeds	~100 miles/h
Conventional firestorm	~220 miles/h

Cloud Altitude





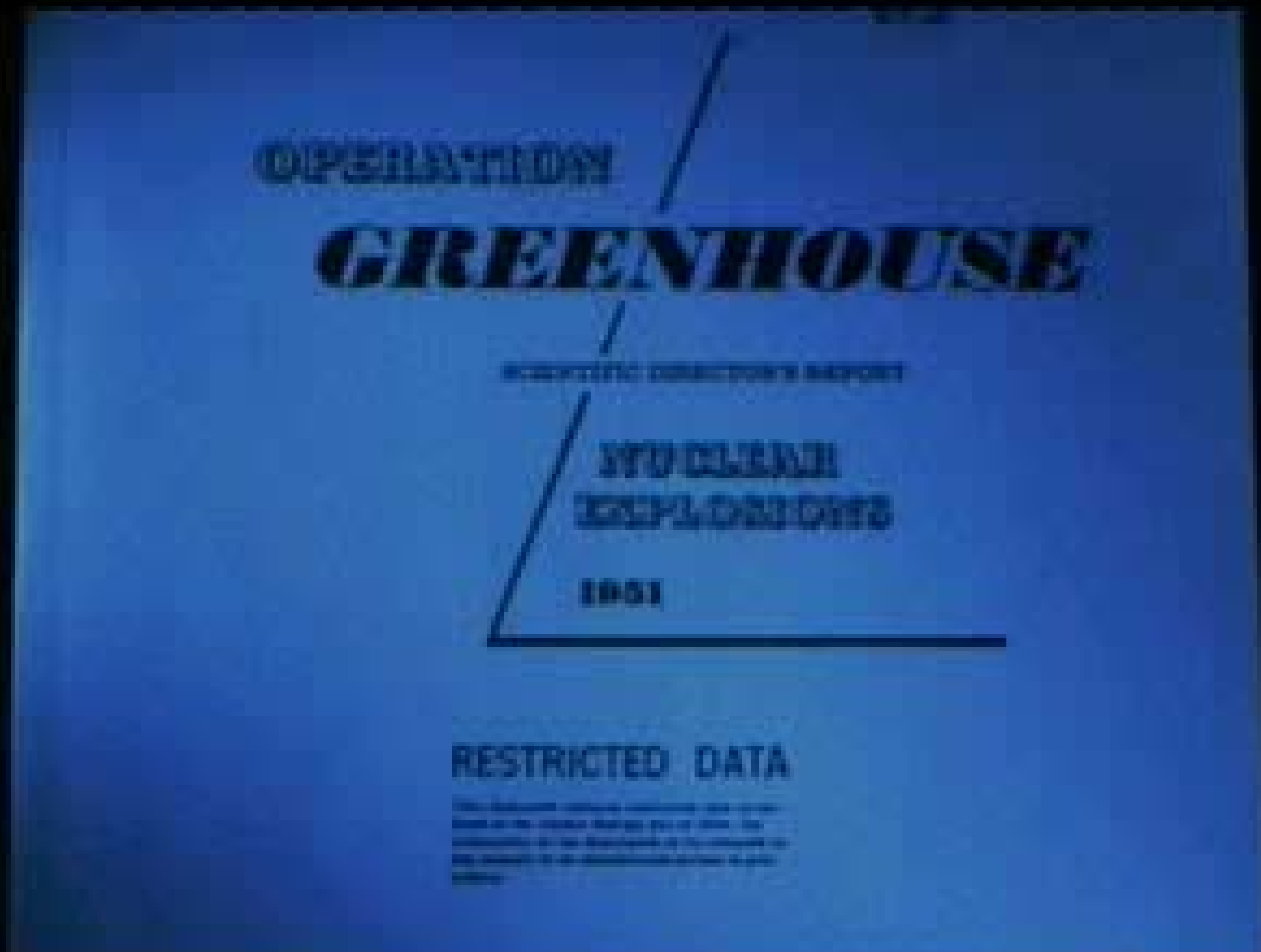
Maximum altitude for cloud rise is reached after ~ 4min.

RATE OF RISE OF THE RADIOACTIVE CLOUD FROM a I-MEGATON AIRBURST

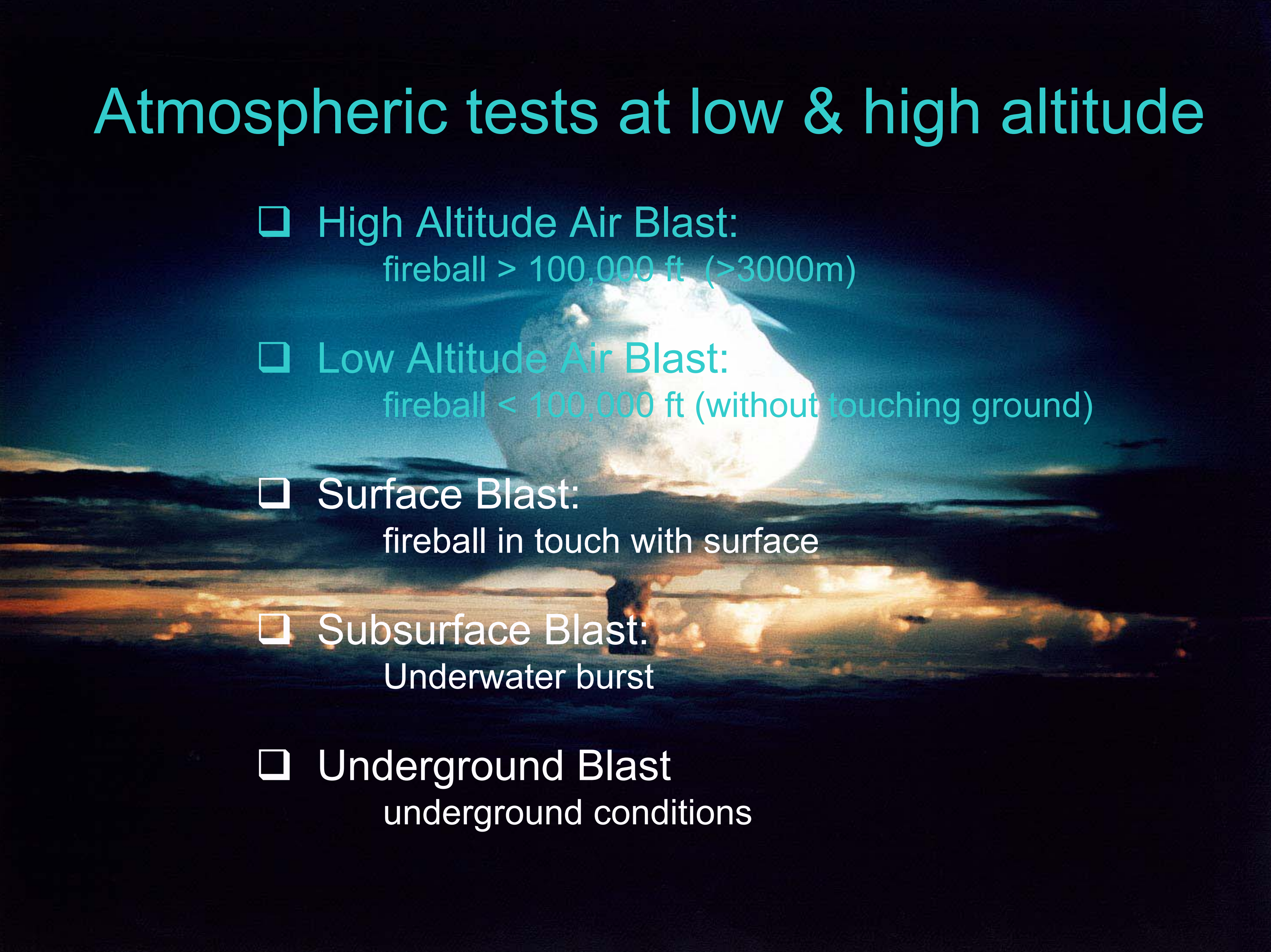
Height (miles)	Time (min)	Rate of Rise (mph)
2.0	0.3	330
3.0	40.7	270
4.0	61.1	220
5.0	102.5	140
6.0	123.8	27

Cloud height & cloud radius depend on the magnitude of the explosion, increase of both radius & height scales with explosion yield.

Operation Greenhouse



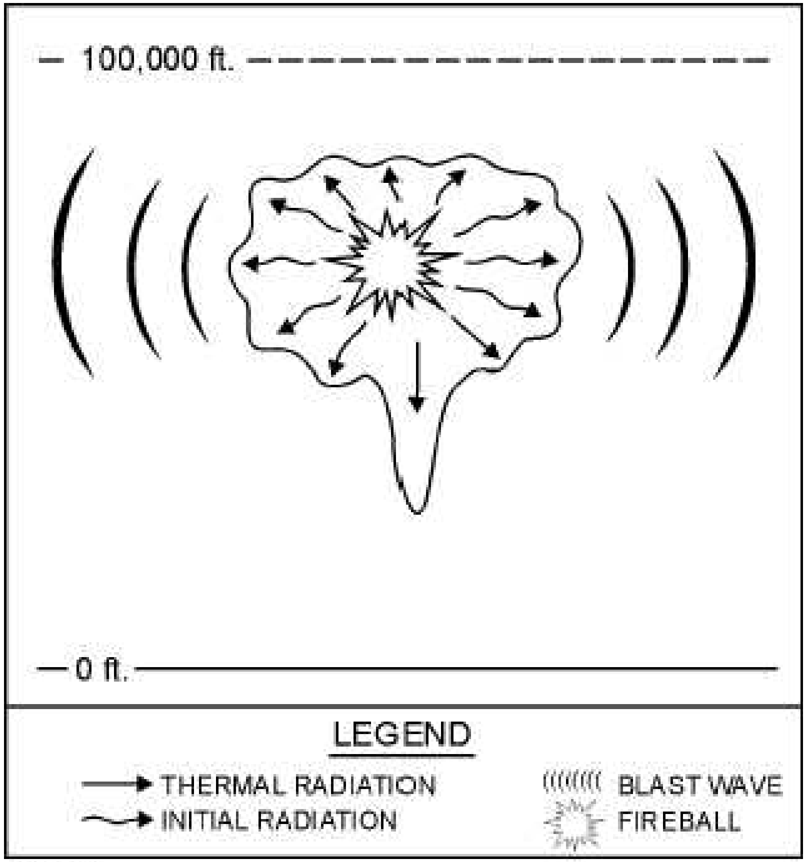
Operation Plumbbob



Atmospheric tests at low & high altitude

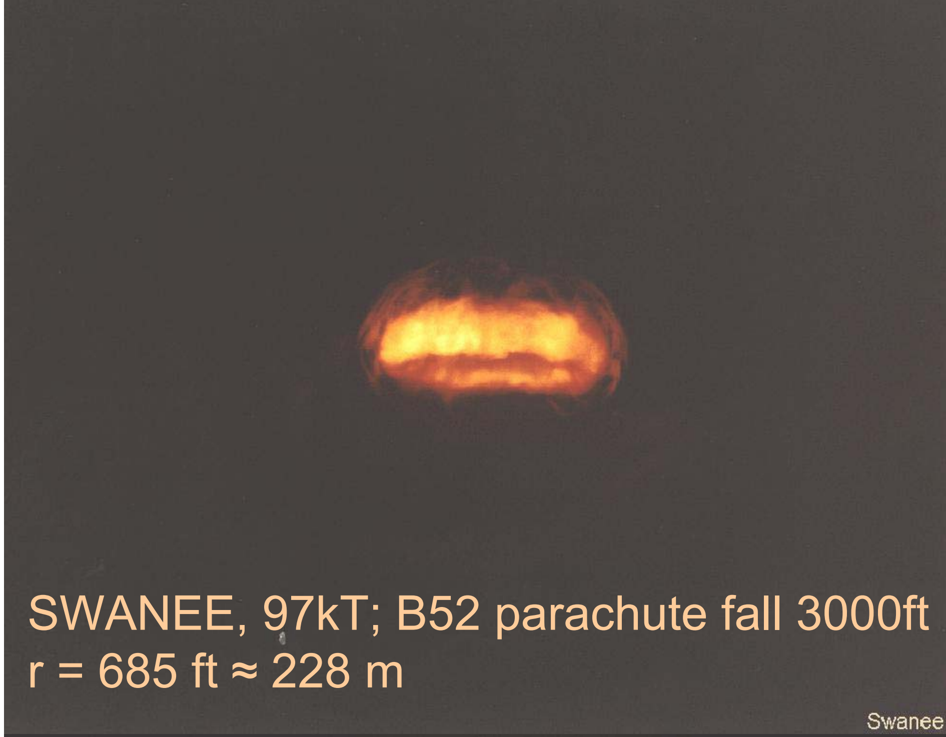
- High Altitude Air Blast:
  fireball > 100,000 ft (>3000m)
- Low Altitude Air Blast:
  fireball < 100,000 ft (without touching ground)
- Surface Blast:
  fireball in touch with surface
- Subsurface Blast:
  Underwater burst
- Underground Blast
  underground conditions

Low Altitude Tests



BMRF1302

Pressure surge downward, shock front emission: Fireball evolution
R = 110 W$^{0.4}$ [ft] (W = yield in kT of TNT)



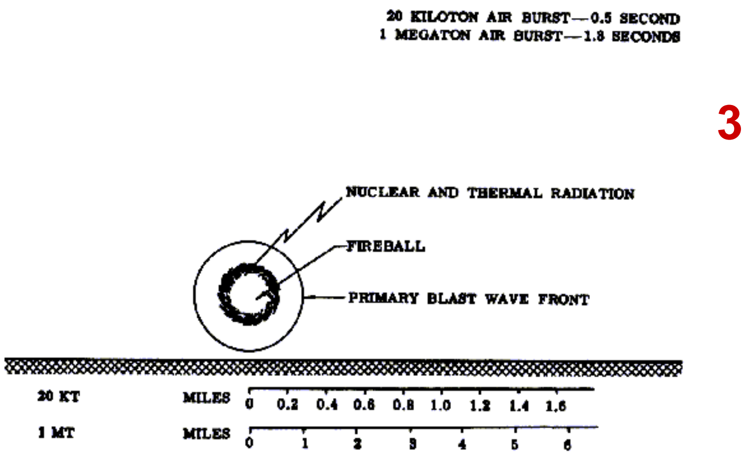
Event: Yukon

Date: May 8, 1962

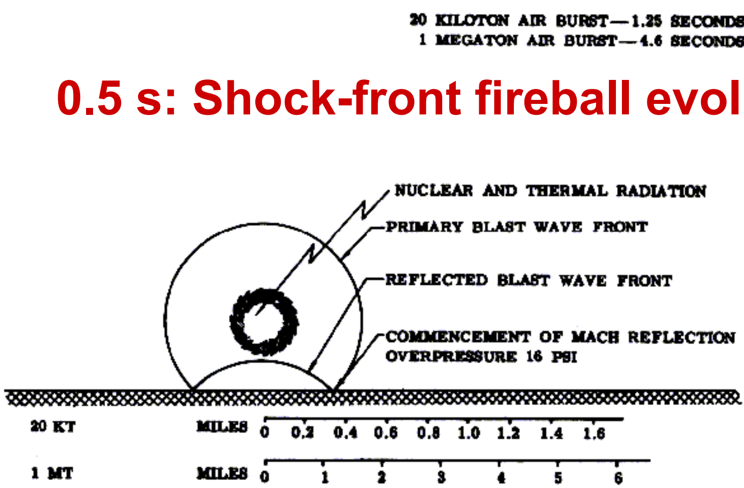
Yield: 100 Kilotons

$r = 110 \cdot W^{0.4} = 694\ \text{ft} \approx 230\ \text{m}$

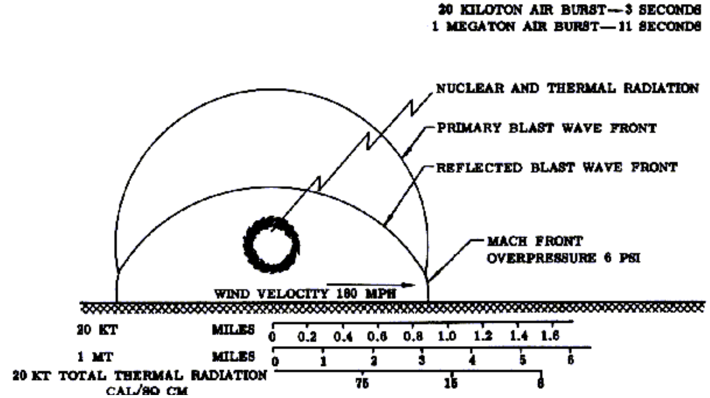
Development of the Airburst



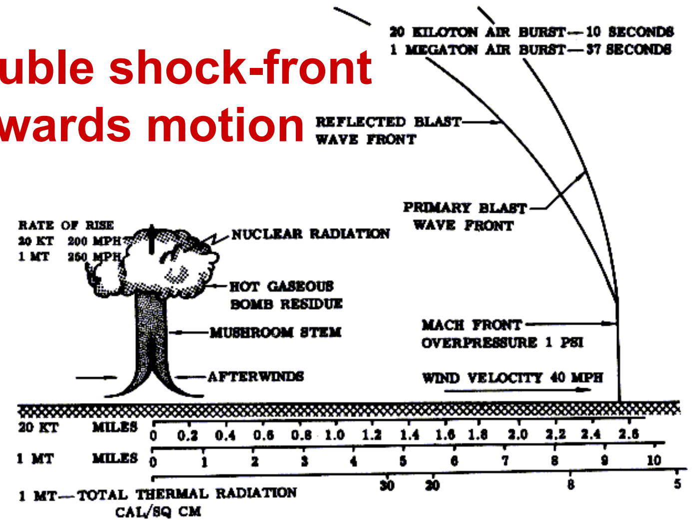
0.5 s: Shock-front fireball evolution

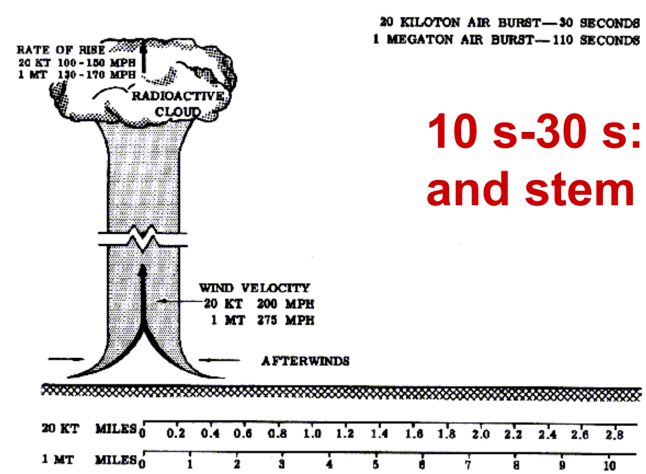


1.2 s: Shock-front re-bounce



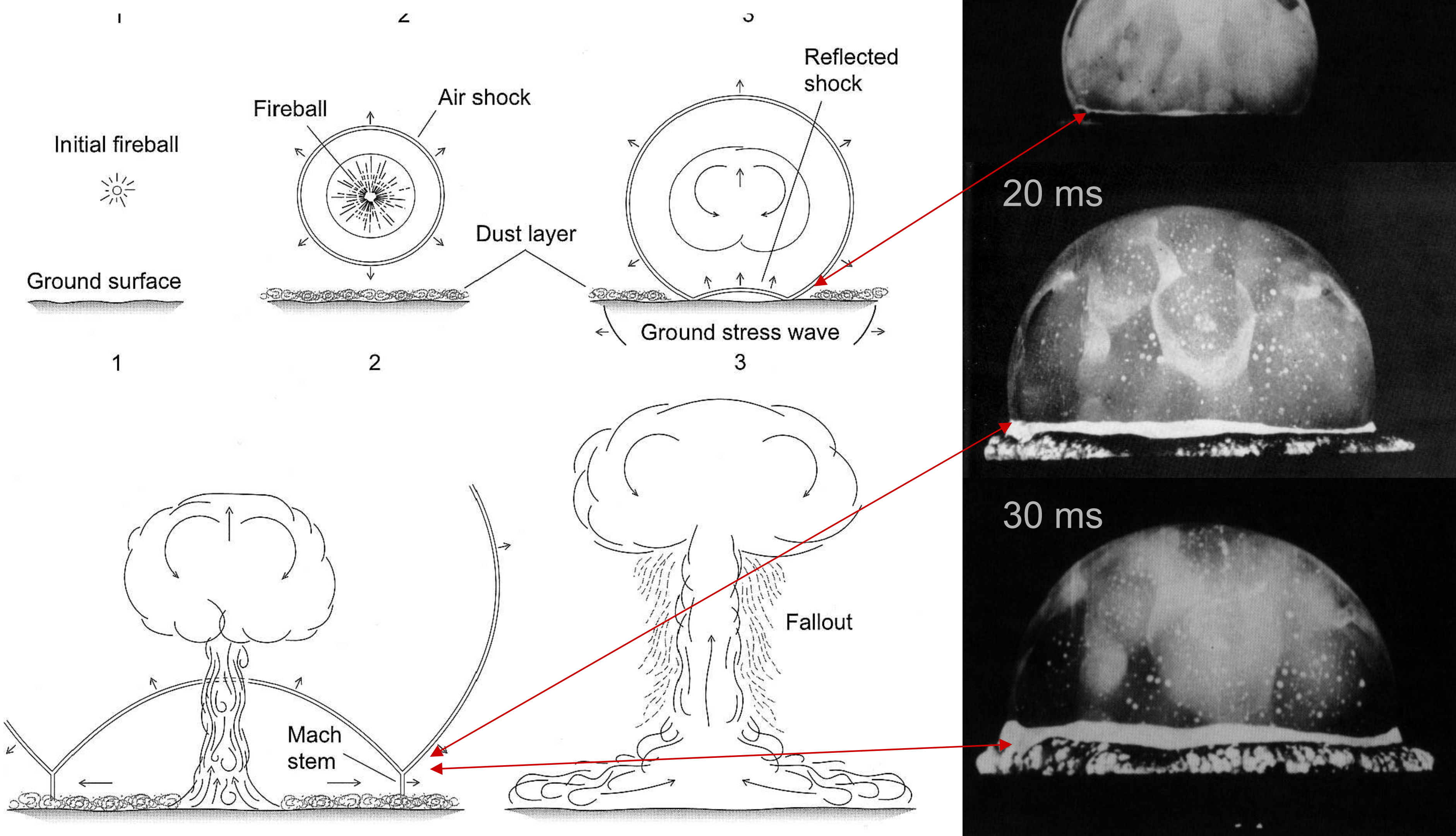
3 s: double shock-front upwards motion





10 s-30 s: Surge and stem evolution

Model



225 kT GEORGE test
Opertion Greenhouse

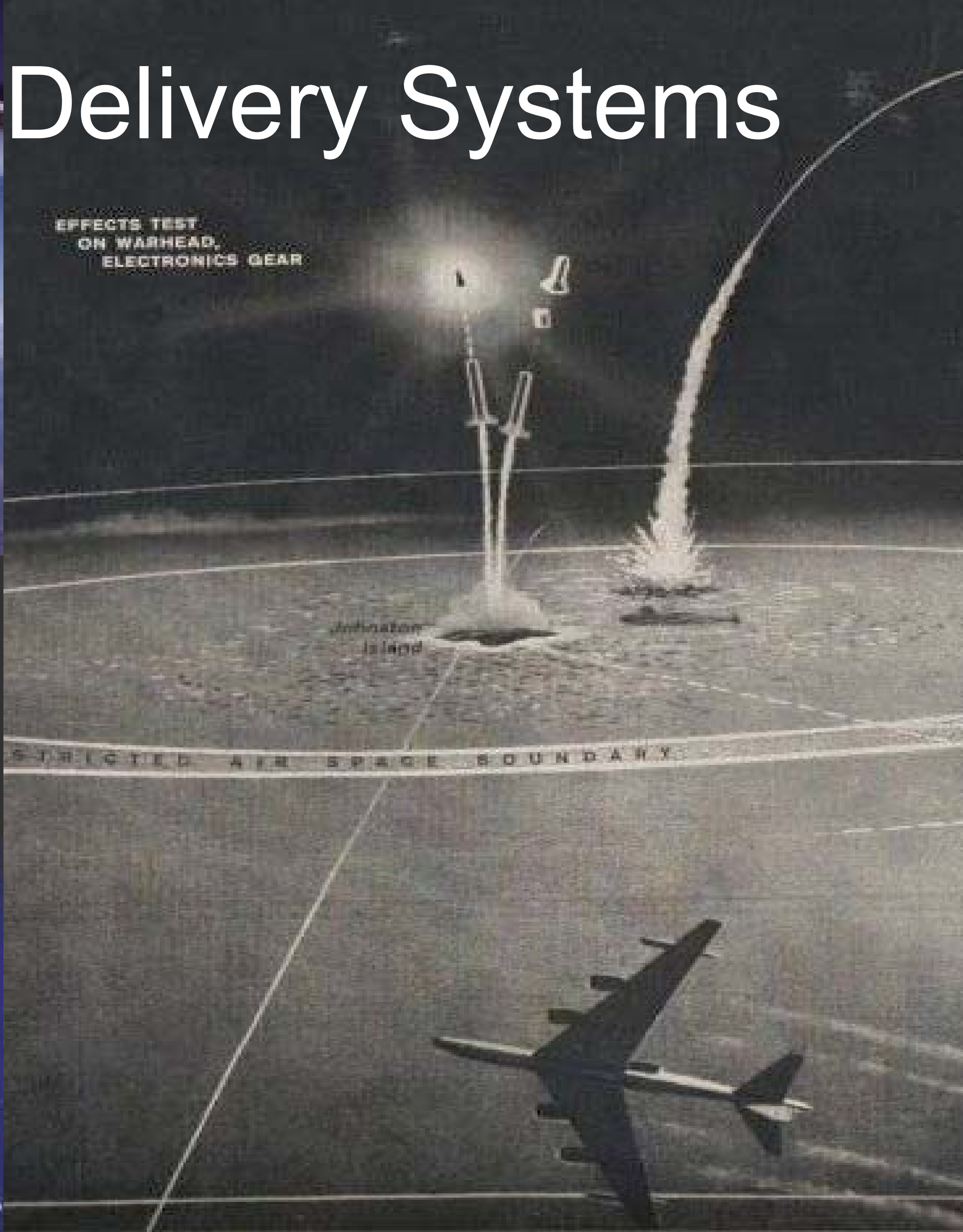
ATOMIC WEAPONS
ORIENTATION PARTS 5 and 6

EFFECTS OF ATOMIC WEAPONS

A SPECIAL WEAPON
ORIENTATION : THE
THERMONUCLEAR WEAPON

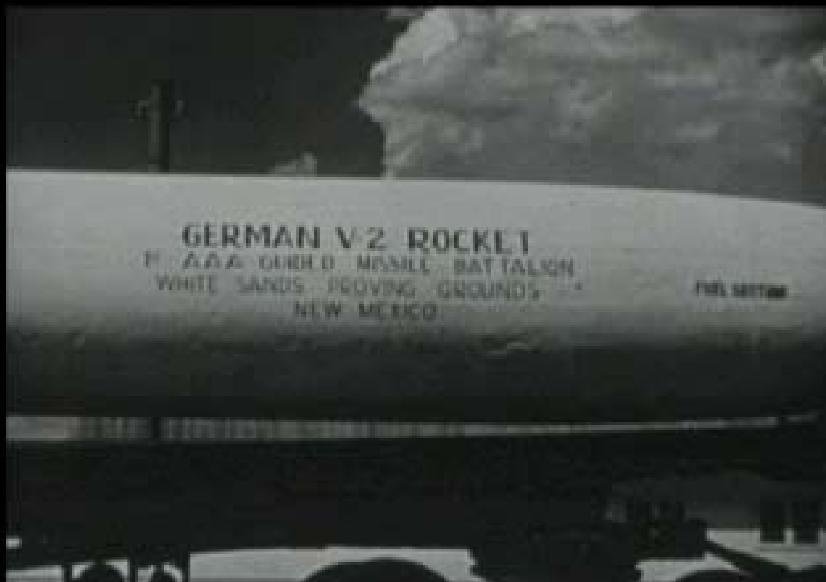
FILM #0800070
(Two Films Combined)

Altitude Test Delivery Systems



Early planning and developments

Germany invested successfully in long range missile systems during WW II
In the believe to invest into a crucial weapon for final victory. However, the



limitations in transport capabilities were too severe to allow sufficient load on explosive material. The production was limited, 1000 V2 missiles were employed, but the final impact on the war development was negligible.

ICBM developments

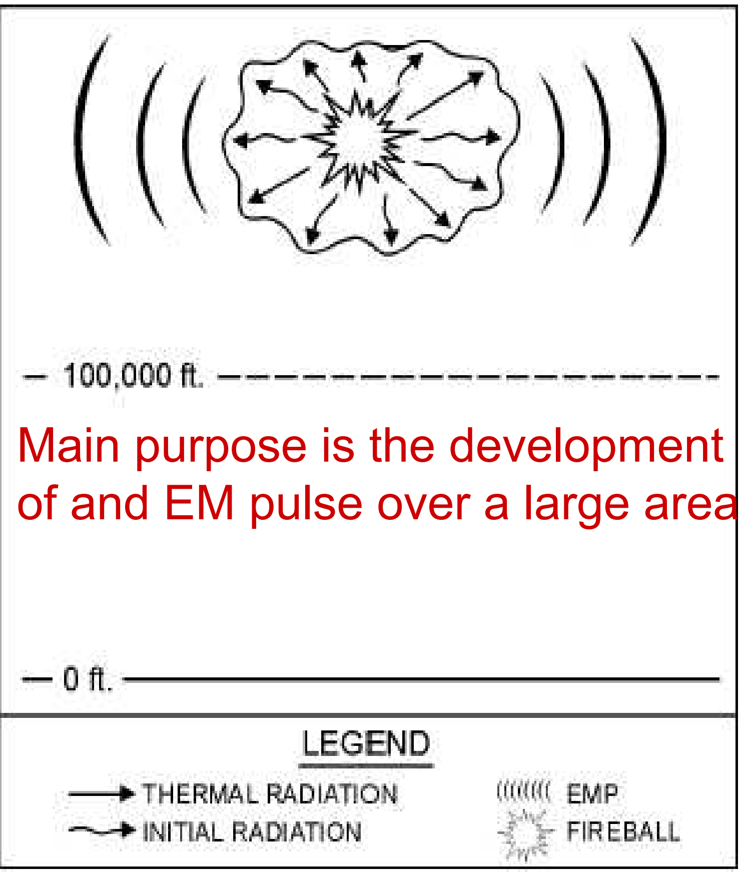
After the Soviet success with Sputnik, US sought for development of Intercontinental Ballistic Missiles (ICBM) to complement the bomber fleet and address the new challenge. US military success was limited until NASA took over the missile development.

Success at last!

High Altitude tests

e.g. Dominic tests on the Christmas Island 1962 shortly before test ban in 1963;

The electromagnetic pulse (EMP) from these tests sent power line surges through Oahu, knocking out street lighting, blowing fuses and circuit breakers, and triggering burglar alarms.

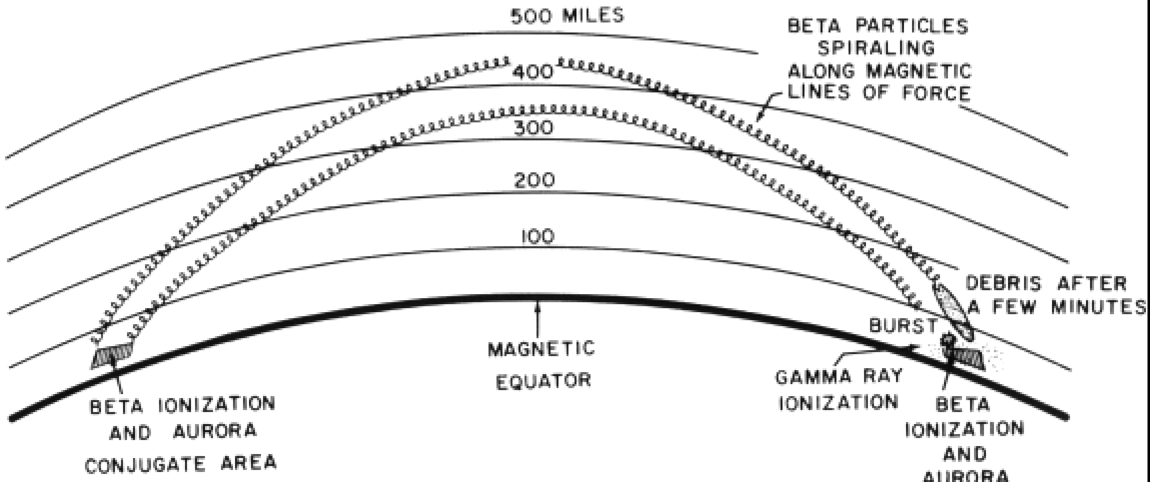


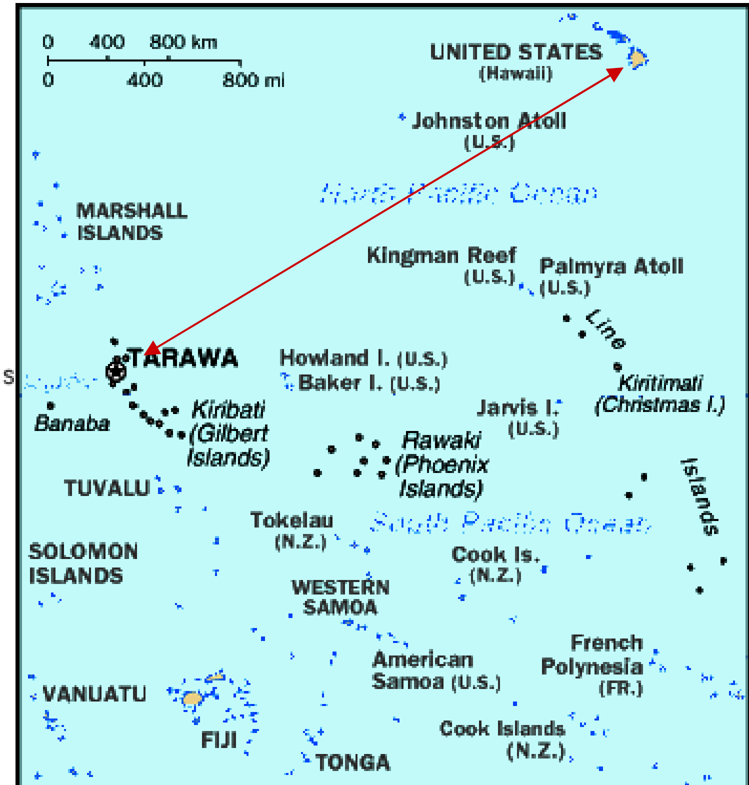
Main purpose is the development of and EM pulse over a large area

KINGFISH,
1962; 1000 kT
Thor Missile Airburst;
320,000 Feet

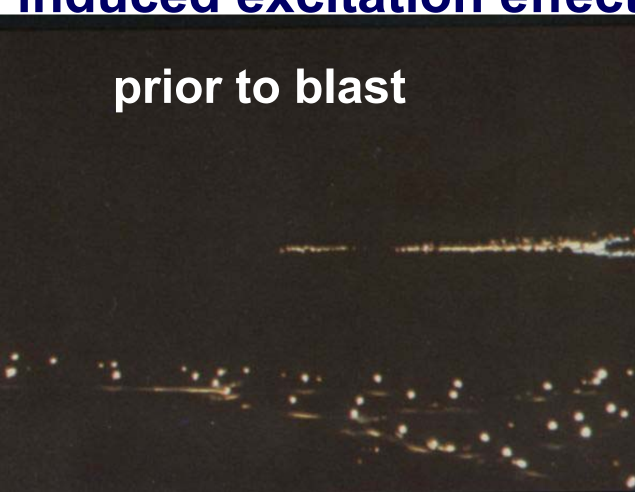
STARFISH PRIME,
1962; 1450 kT
Thor Missile airburst;
248 miles,

Long distance observation





The blast from Starfish was seen at 800 miles distance from Honolulu, Hawaii. Originated Auroral light phenomena through β-radiation induced excitation effects in atmosphere.



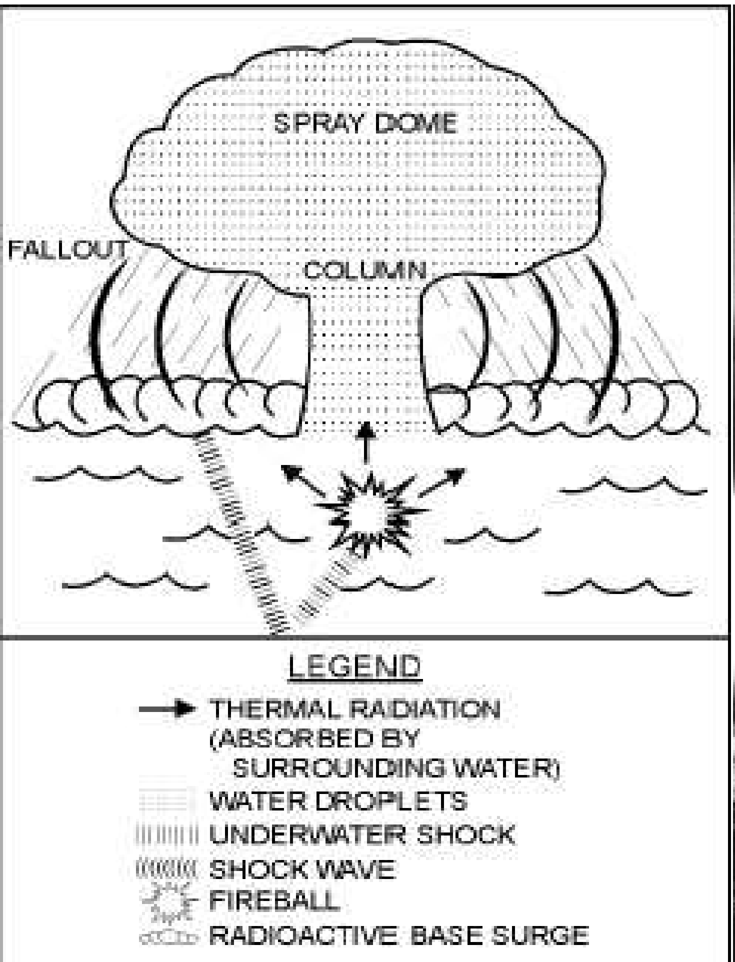
High Altitude Tests

Atmospheric Effects

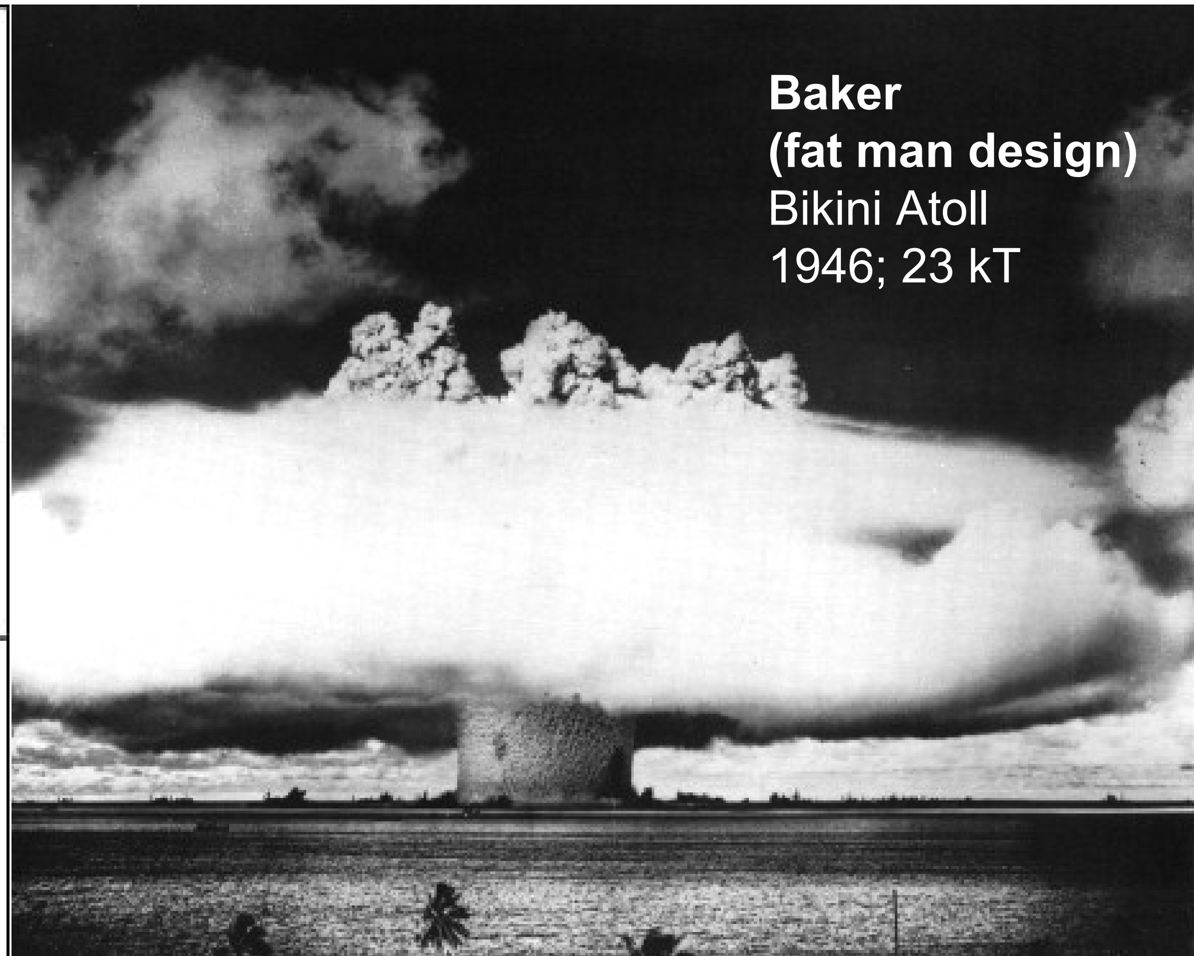
Underwater Blasts

Cloud formation in underwater tests

Formation of spray dome & condensation cloud from erupted water



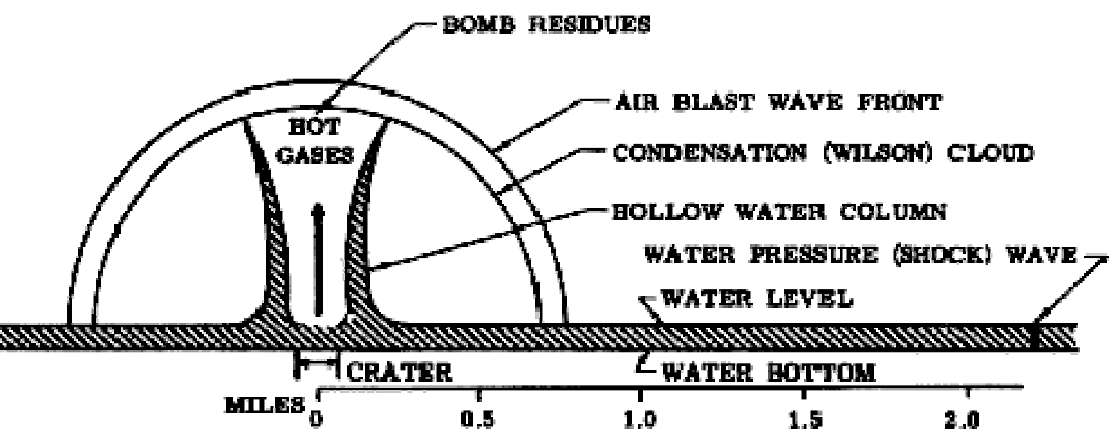
BMRF1304



Baker
(fat man design)
Bikini Atoll
1946; 23 kT

First Moments

- Eruption through water surface
- Formation of spray dome (4 ms)
- Spherical cloud condensation (1 s)
- Break through of erupted water



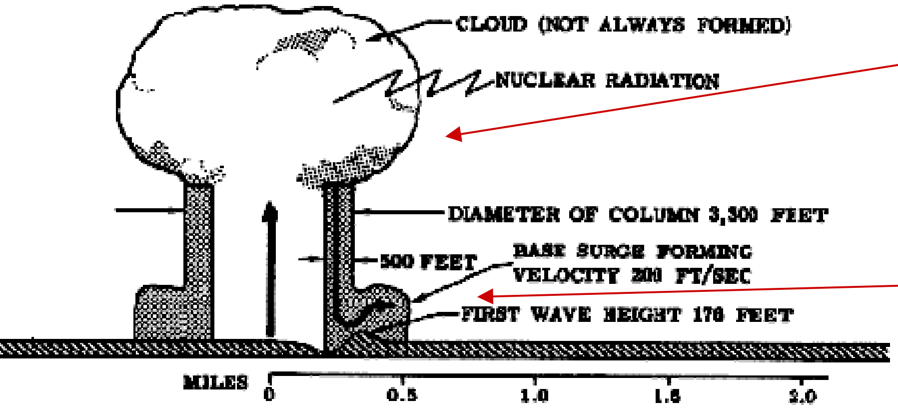
2.80a. Chronological development of a 100-kiloton shallow underwater burst: 2 seconds after detonation.

- formation of base surge (2 s)

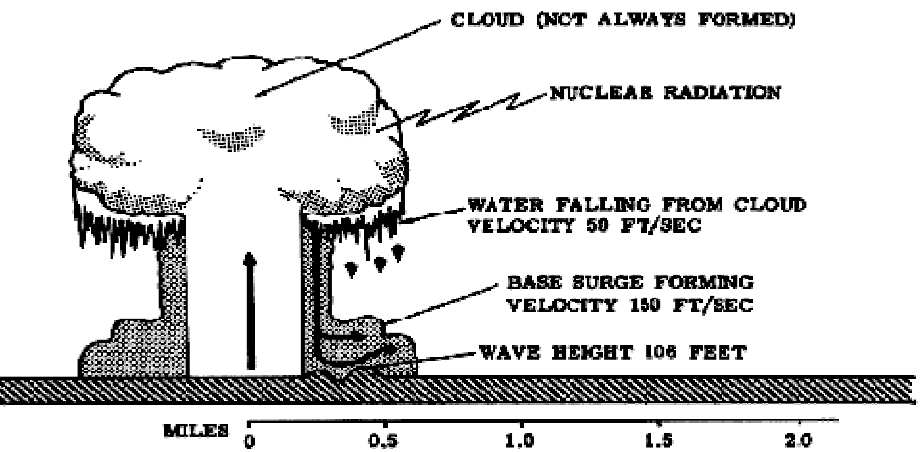
The formation of surge & cloud

Cloud development

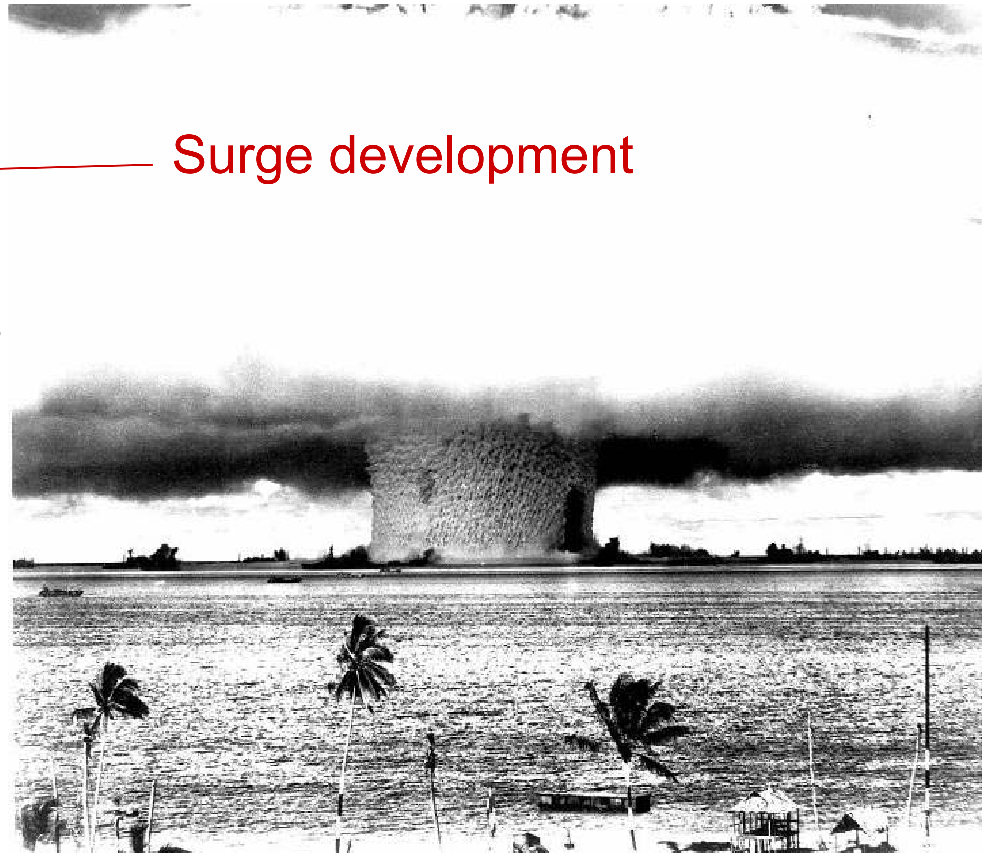
Surge development



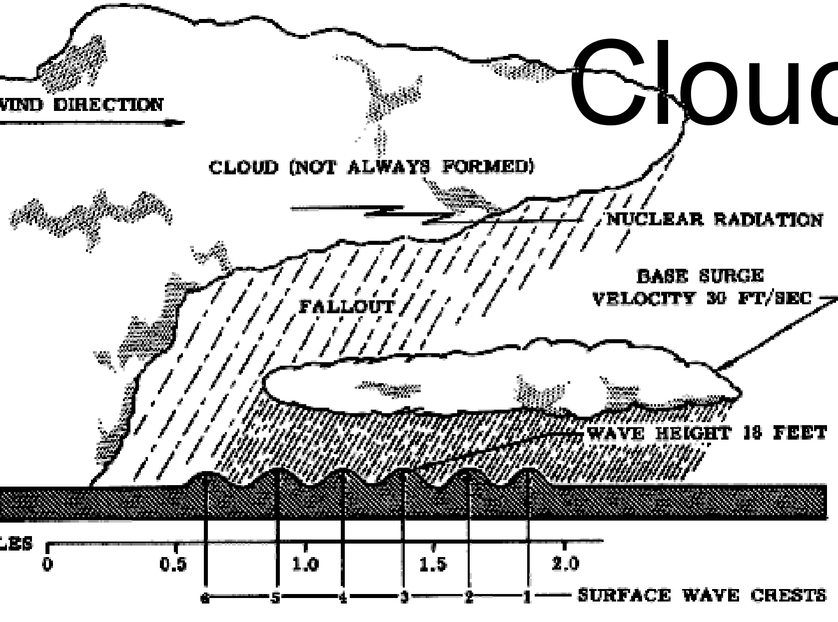
2.80b. Chronological development of a 100-kiloton shallow underwater burst: 12 seconds after detonation.



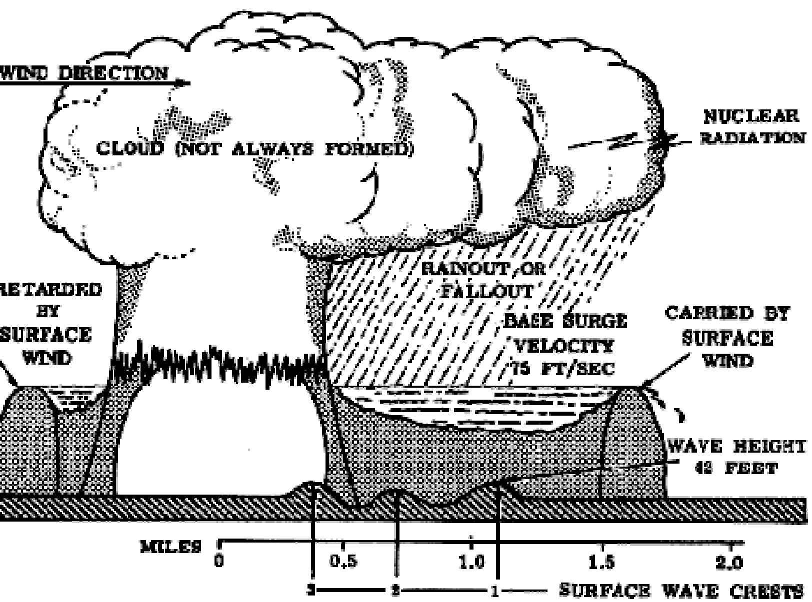
2.80c. Chronological development of a 100-kiloton shallow underwater burst: 20 seconds after detonation.



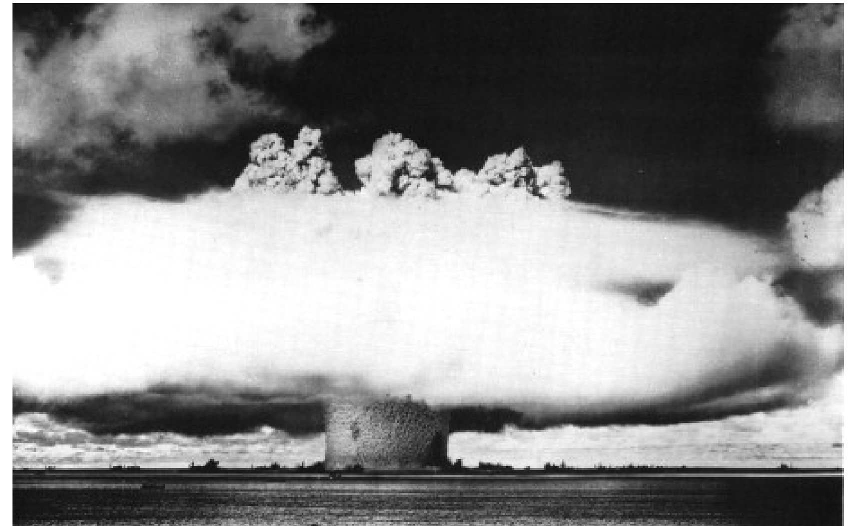
Cloud expansion & fallout

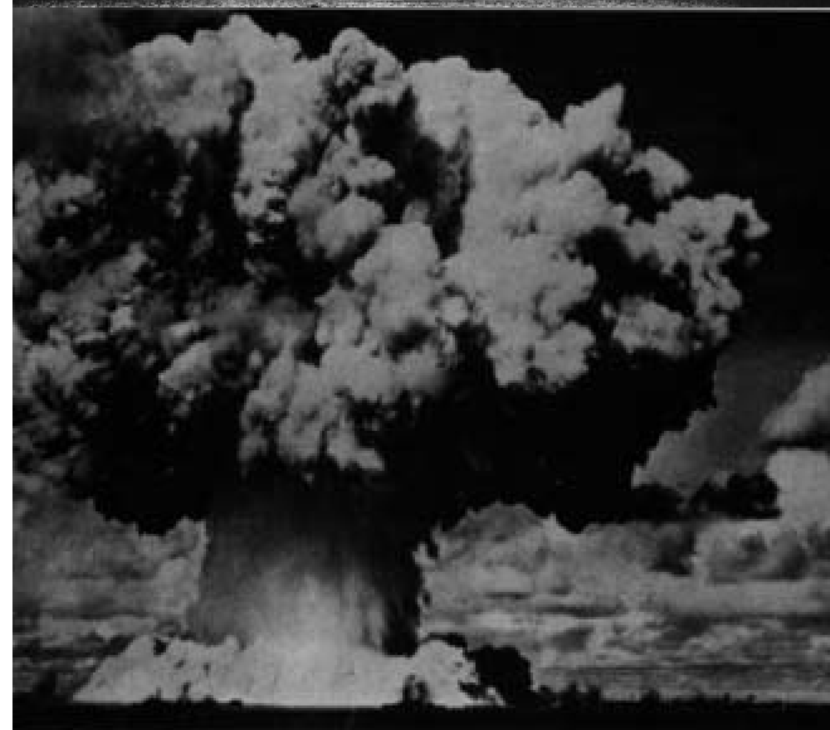


2.80e. Chronological development of a 100-kiloton shallow underwater burst: 2.5 minutes after detonation.

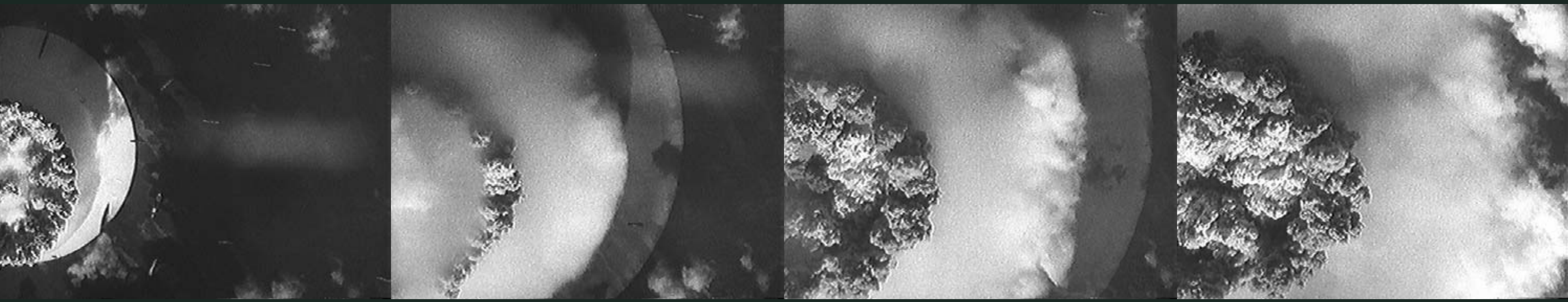


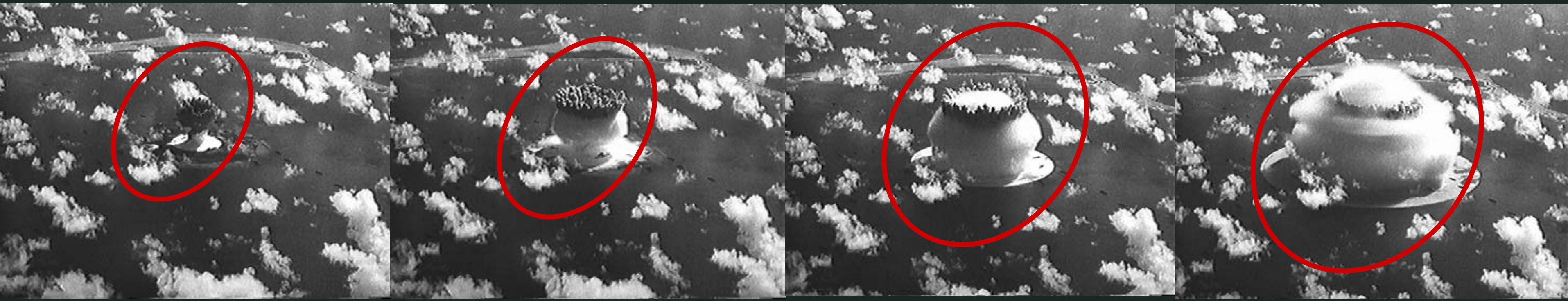
2.80d. Chronological development of a 100-kiloton shallow underwater burst: 1 minute after detonation.





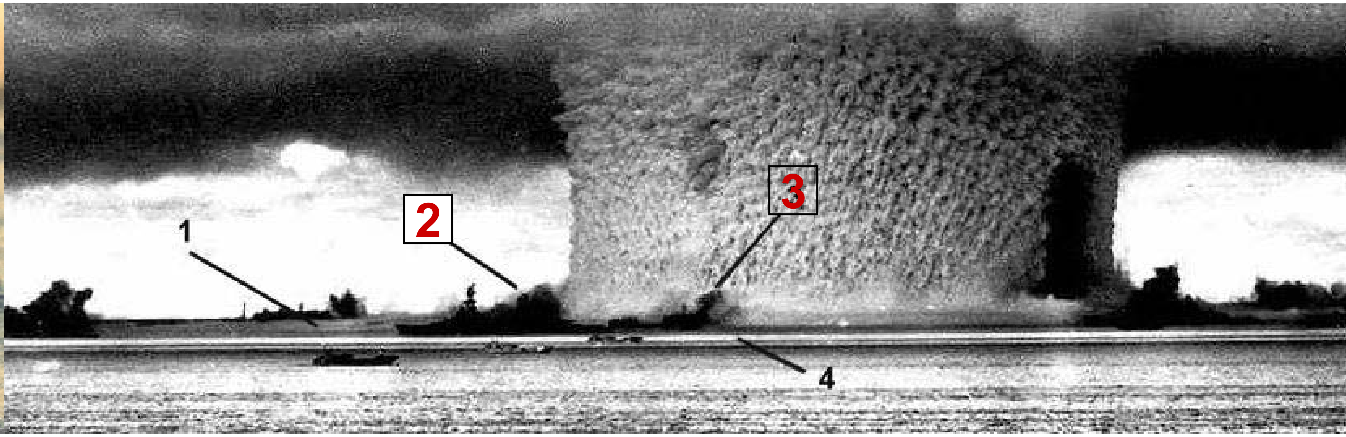
Cloud Evolution





The Baker test

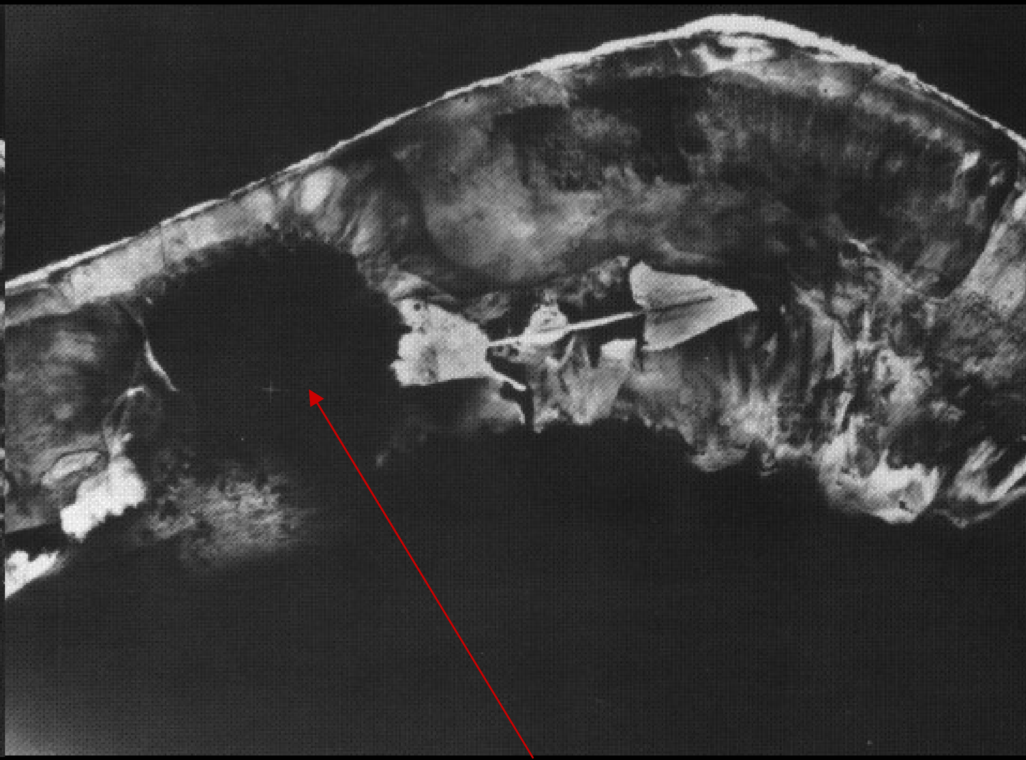
These were the first "weapons effects" tests ever conducted - tests designed specifically to study how nuclear explosions affect other things - rather than tests of the behavior of a weapon design (as was Trinity). The purpose of the tests was to examine the effects of nuclear explosions on naval vessels, planes, and animals.



The closest ship to surface zero was the *USS Saratoga*. Eight ships were sunk or capsized, eight more were severely damaged. Sunk vessels were the *USS Saratoga (2 being hit by 90 ft wave, 3 front being swept by wave)*, *USS Arkansas*, the *Nagato*, LSM-60 (obviously), the submarines *USS Apogon* and *USS Pilotfish*, the concrete dry dock ARDC-13, and the barge YO-160.

The damage to the Atoll by Baker and subsequent tests - Bravo

Atoll before the Bravo test



Atoll after the Bravo test

Population had been removed, numerous tests followed until the early sixties
Entire island is contaminated with radioactivity; population is still not allowed to return: 2001 the US government granted $563,315,500 reparations to the Bikinians.
For details see: http://www.bikiniatoll.com/home.html

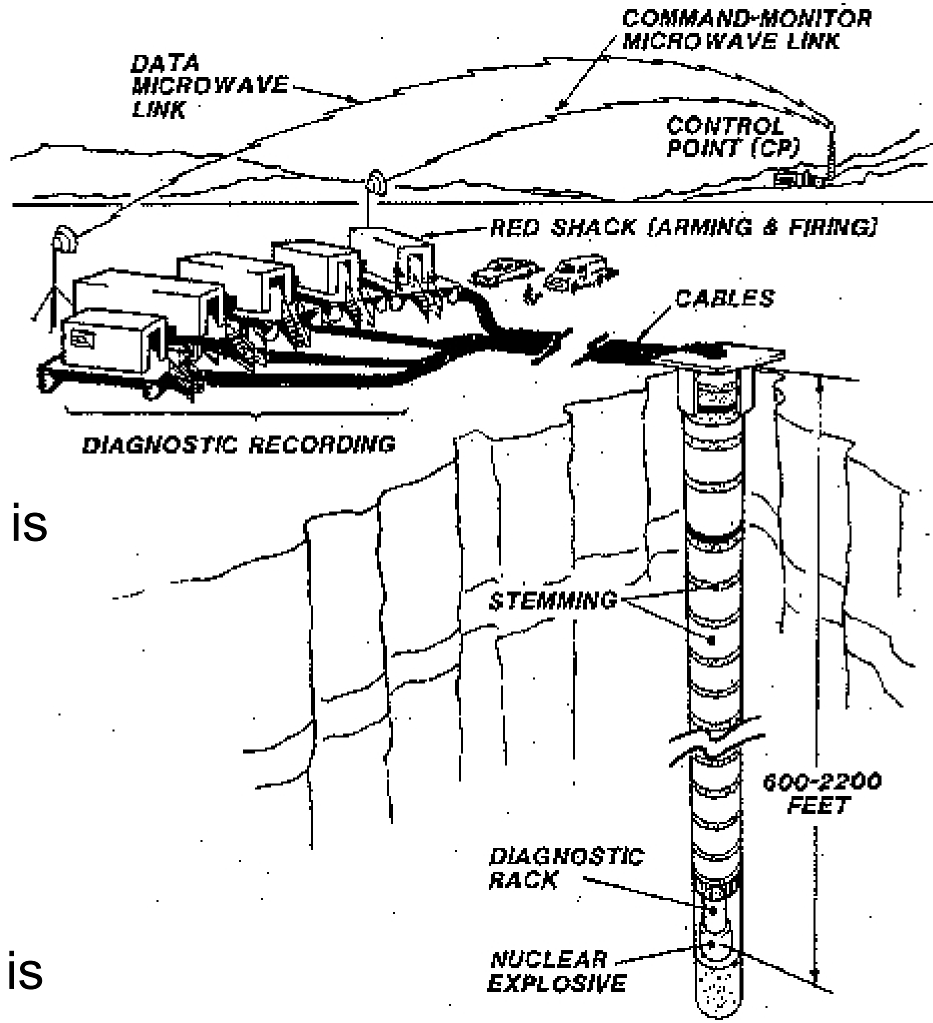
Underground test procedure

Underground tests required careful preparation and monitoring. Hole depth and diameter are dictated by anticipated yield.

Depth range: 600 – 2200 feet
Diameter range: 48 – 120 inches

Containment of radioactivity in hole is required; geological survey is necessary prior to test. Hole is stemmed after device is positioned.

Underground cavity forms after explosion. Cavity drops forming chimney. If the strength of chimney is exceeded by weight of overburden, chimney collapses forming a crater.



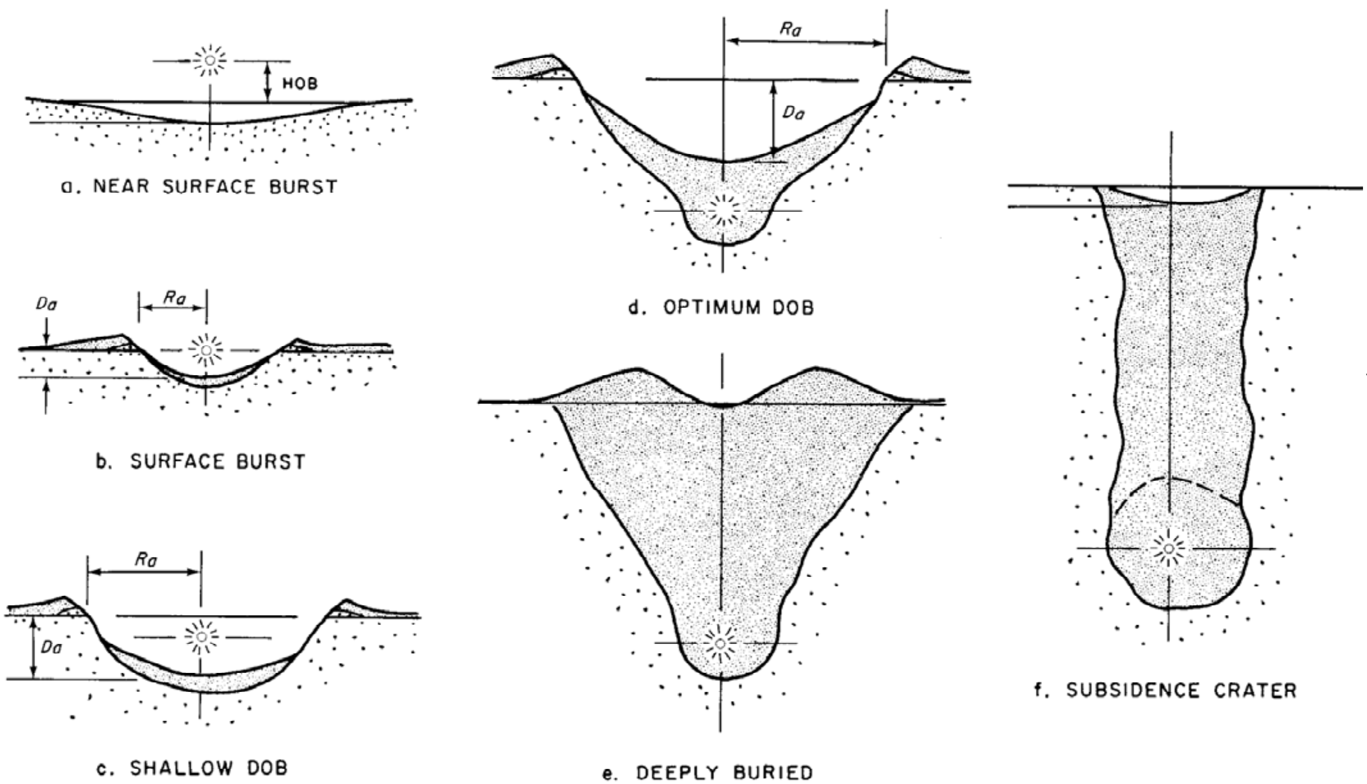
SEDAN Preparations & Success

1962 Test to investigate “peaceful applications such as large scale construction efforts

- Harbor building
- Mountain removal

Underground test

In underground tests most of the released energy goes into crater formation. Only a fraction of the energy goes into blast depending on explosion depth. The shape of the crater depends on depth of explosion; new applications are bunker breaking small nuclear weapon developments.



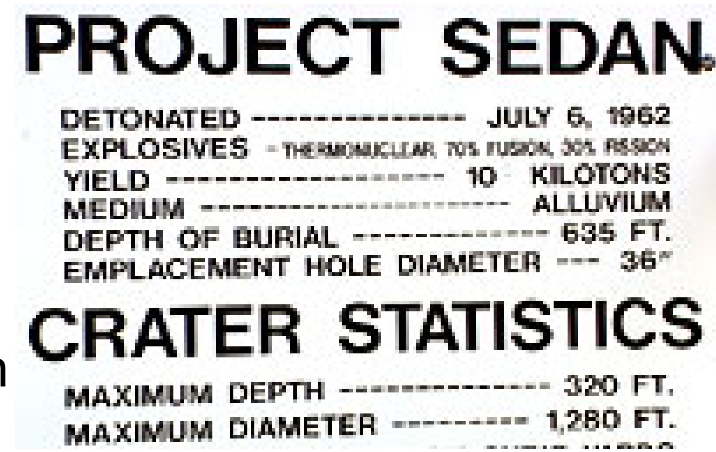
Crater volume:
$V_c \approx 10^5 \cdot W \ m^3$

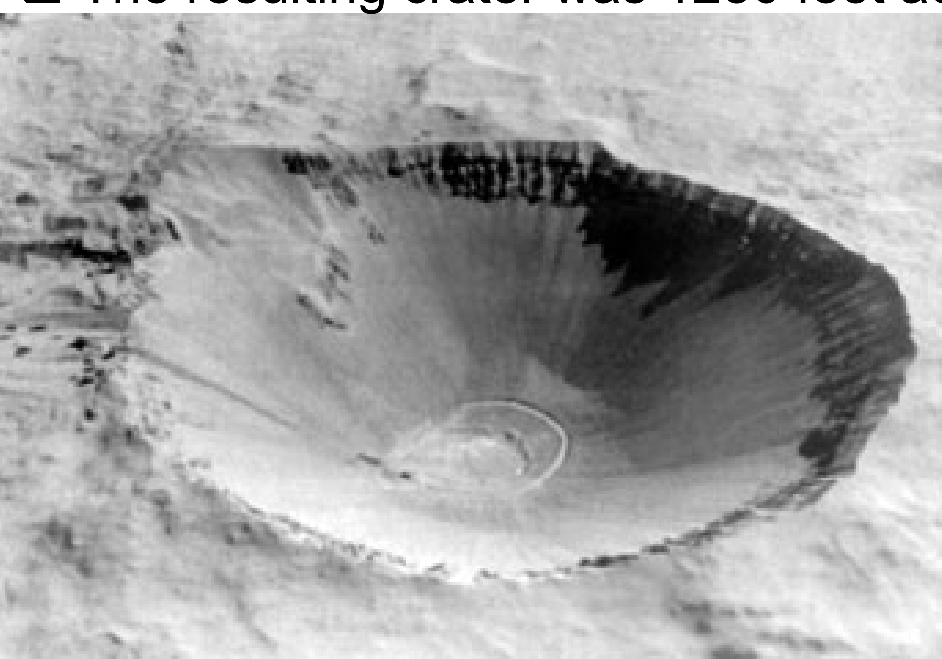
Relative crater sizes and shapes resulting from various burst depths; R_a and D_a are the apparent radius and depth, respectively, of the crater

SEDAN EVENT

Sedan test parameters and results

- ❑ The **104 kT** thermonuclear device was buried **635 feet** below ground level.
- ❑ The force of the detonation released seismic energy equivalent to an earthquake of 4.75 magnitude on the Richter Scale.
- ❑ The blast moved 6.5 million cubic yards of earth and rock up to 290 feet in the air.
- ❑ The resulting crater was 1280 feet across and 320 feet deep.



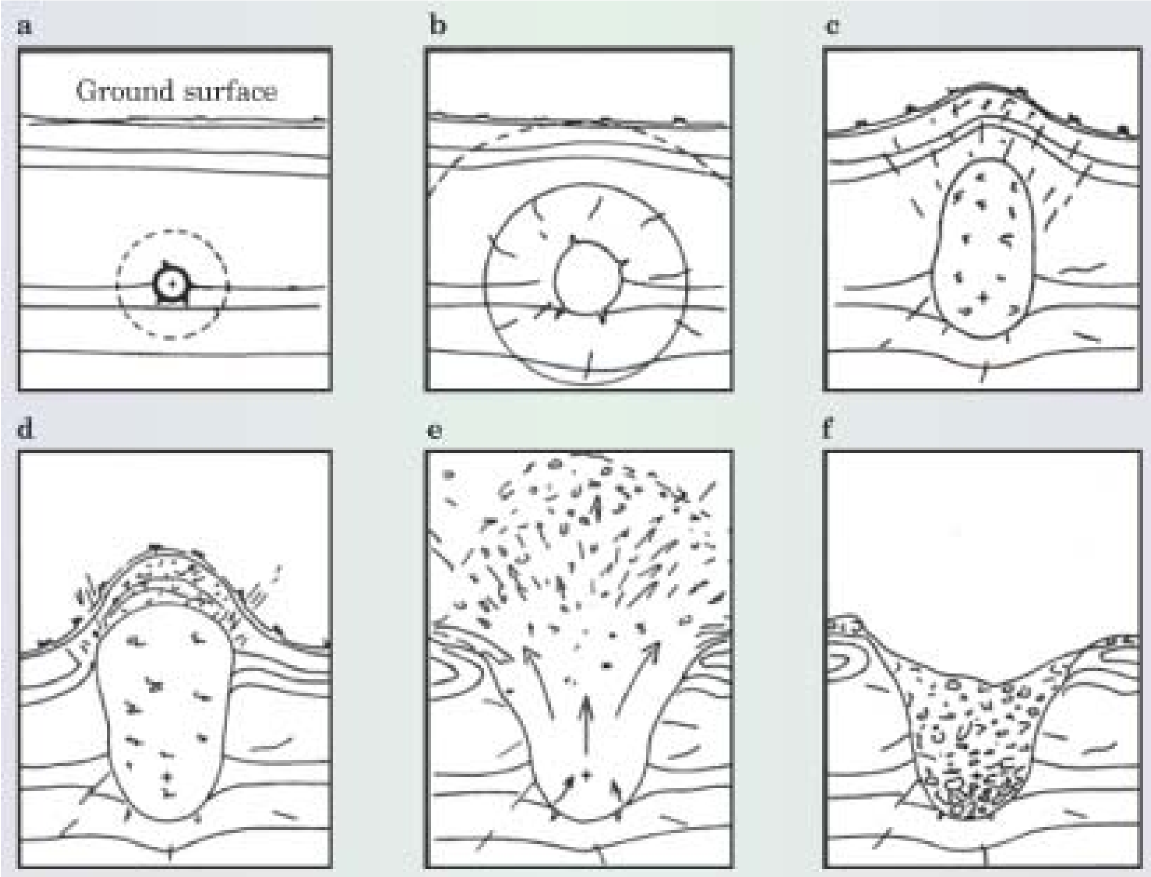


Crater formation in underground test

Blast vaporizes material within radius $r=2\cdot W^{1/3}$ m (W in kilotons (kT) of TNT)

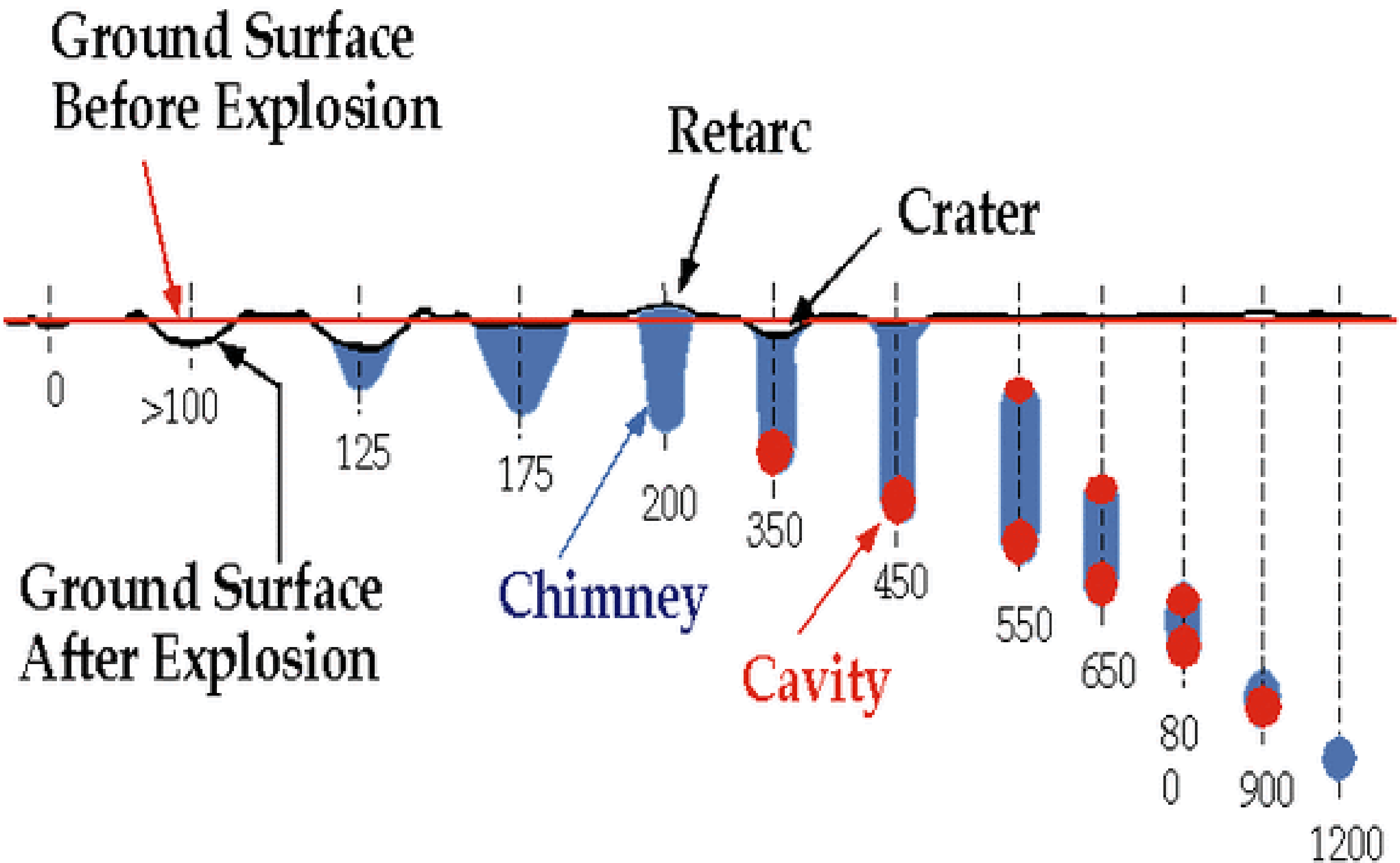
Blast melts material within $r=4\cdot W^{1/3}$ m

Blast induced seismic shock crushes material within $r=50\cdot W^{1/3}$ m



Gas release and seismic waves cause eruption and crater formation. Crater volume $V_c \approx 10^5\, W\ m^3$. (Example Sedan ~10million m^3)

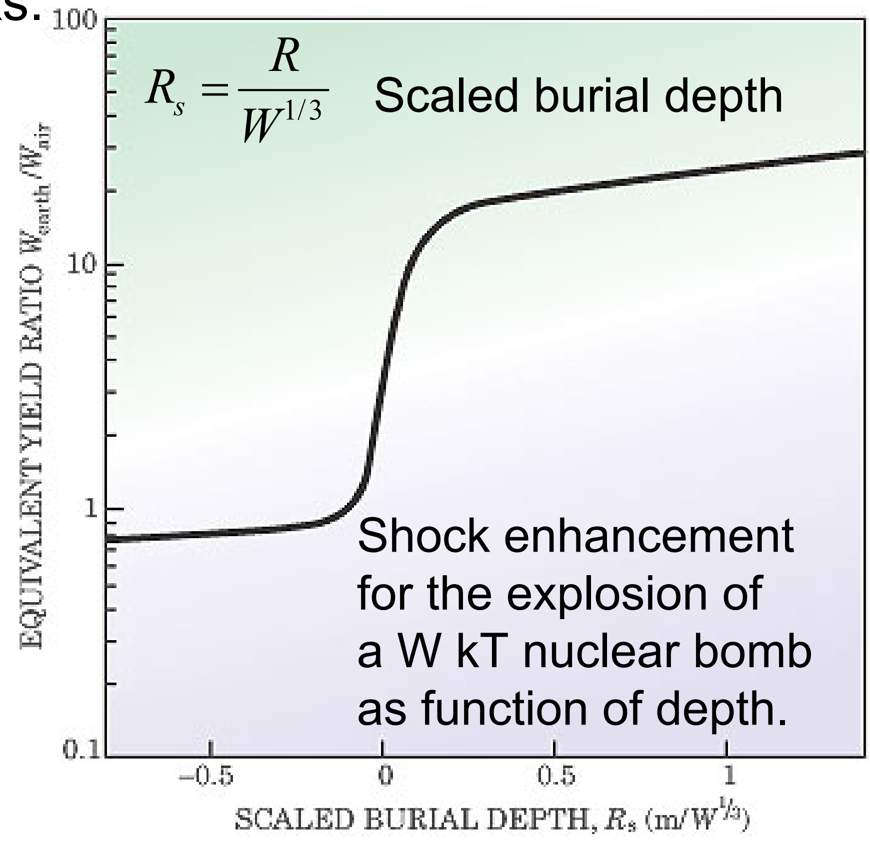
Nuclear Cratering



Crater Building

Nuclear Bunker Busters

Needs to contain most of the released energy underground to break structure by underground shock and energy release (no air venting). Underground structures are difficult to break, even by surface nuclear explosions. Underground explosion cause ground motion and seismic shocks.



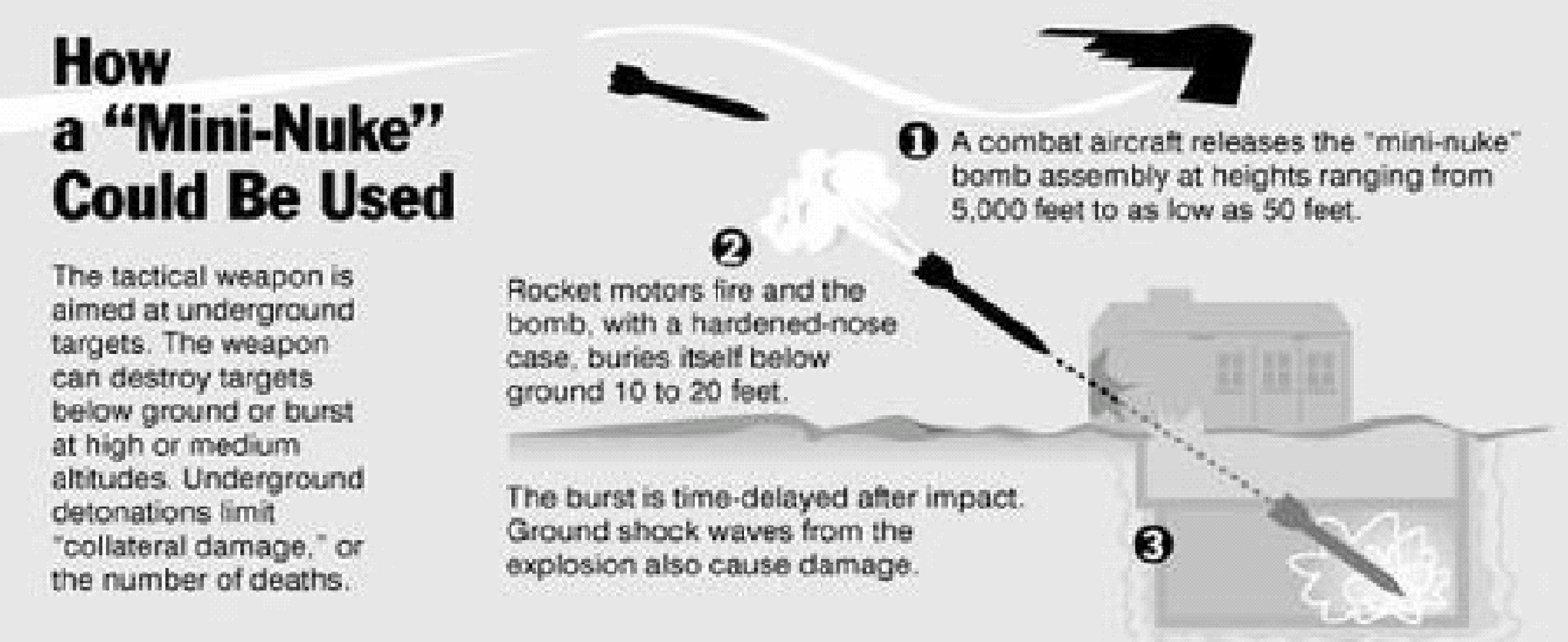
1 kT bomb 1 m underground (R_s=1m) would have same effect as 35 kT bomb 1 m above ground.

Or 10 kt bomb 2 m underground would enhance explosion yield by a factor of 20. (R_s=0.9m)

At low depths most of released energy is lost in blast rather than translated into seismic energy.

bunker breaking nuclear missile systems

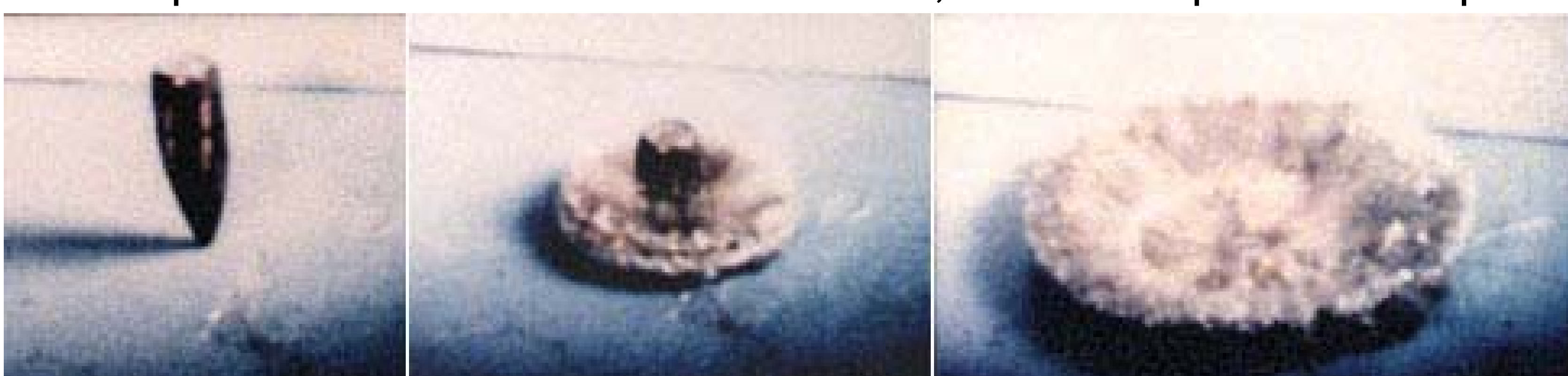
New dreams of the pentagon to address the perceived threat from third world underground “terrorist” bunker systems.



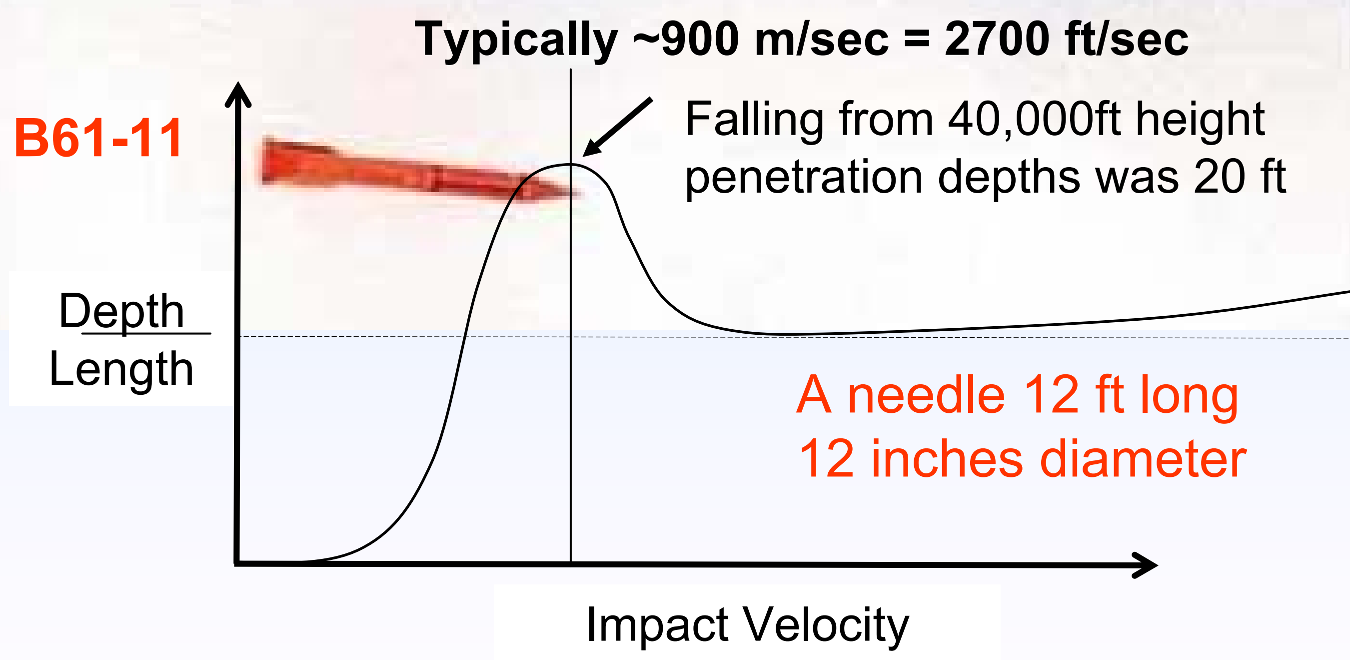

CNN

Penetration limits

2-4 m penetrating depth of missile, most of energy is lost in release to atmosphere rather than in seismic shock, material liquefies at impact.



Long Rod Penetration versus Velocity



Chances

$$\frac{D}{L} \approx \frac{\rho_p}{\rho_T} \cdot \ln\left(\frac{Y_p}{Y_T}\right)$$

ρ: density
Y: material strength

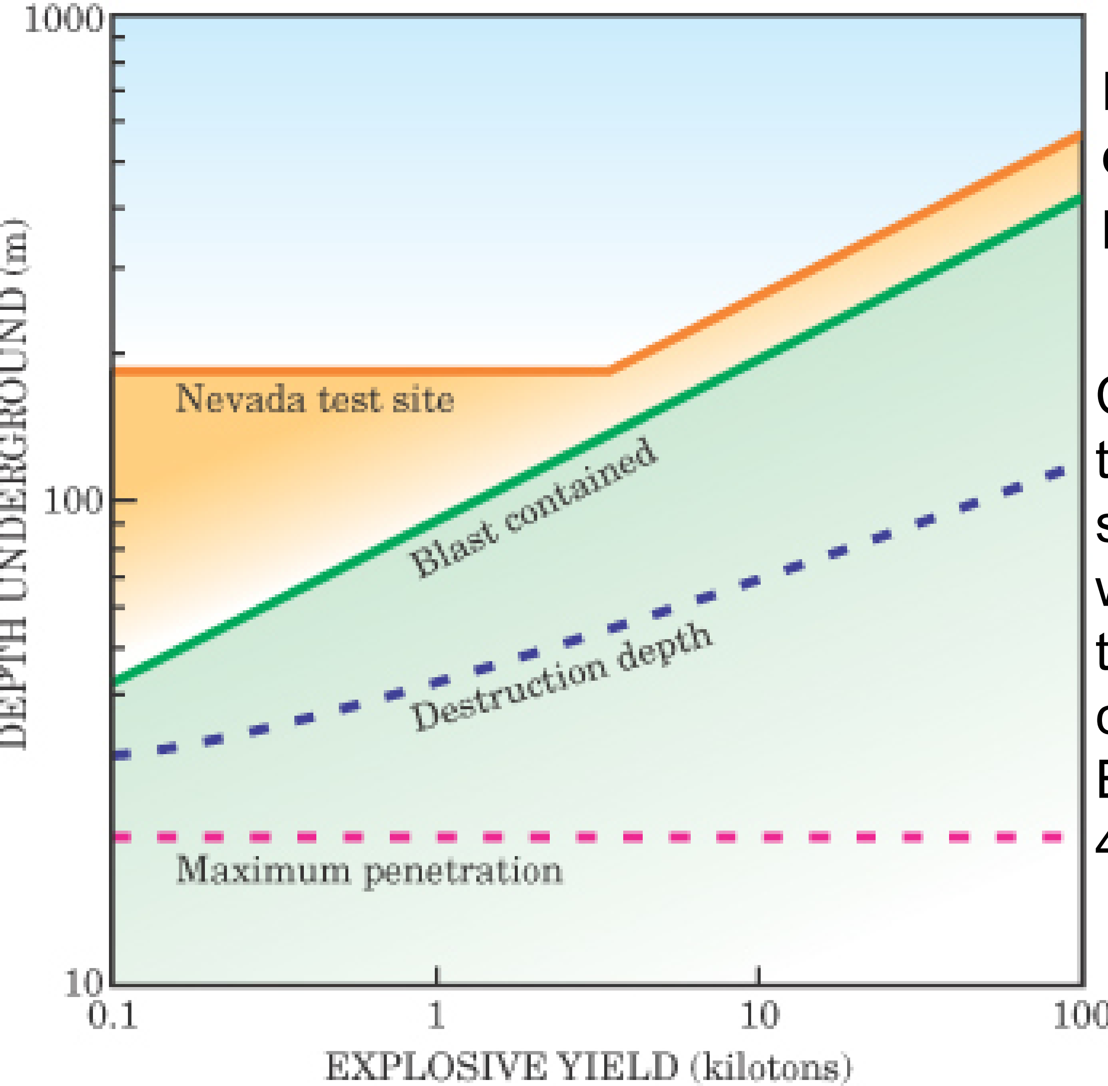
If penetrator material is 2x target material the depth to length ratio is 1.4. A 12 ft long missile penetrates 17 ft.

Significant enhancement in material strength is necessary to improve beyond present means. (factor 100 in material strength and factor 10 in density would reach penetration depth of 46 ft only. B61-11 has special hardened nose.

High Velocity Kinetic Penetration

A GBU-28 undergoes a high-velocity sled test, penetrating several meters of concrete.

Containment of nuclear blast



Natural limit of penetration (set by deformation and liquidisation of penetrating missile ~ 20 m

Containment depth corresponds to explosive yield W. Present standard 300 kT earth penetrating warhead would need to penetrate to 500 m (instead of 20 m) to fully contain the energy underground. Even 0.1 kT warhead needs a 40 m depth for containment.

Bomb test characteristics

The effects of Nuclear weapons
Blast damage
Thermal damage
Radiation damage
EM-pulse
Scaling laws
Protection and shielding

Distance effects
Fall-out
Atmospheric distribution

Effects on population
Radiation effects
Fallout conditions
Short range Medical consequences
Long term medical consequences

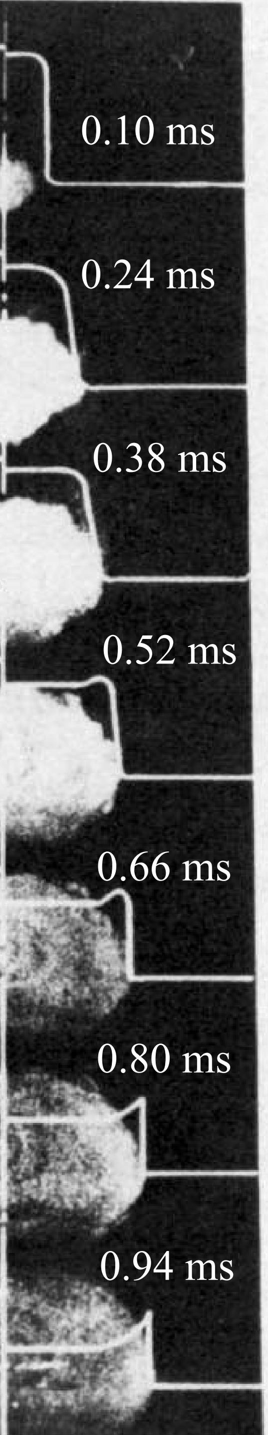
Destructive Effects of Nuclear Weapons

Blast damage
Thermal damage
Radiation damage
EM-pulse

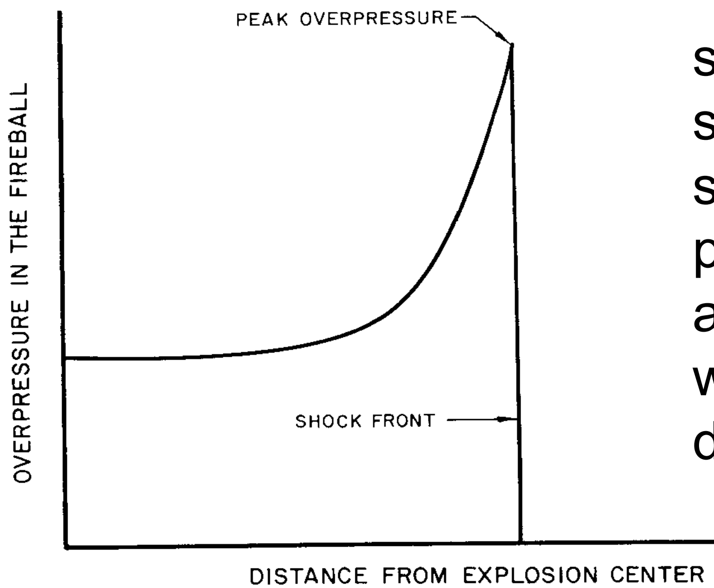
"Thank God, Sylvia! We're alive!"

- The generation of a mechanical shock through sudden increase of pressure causes mechanical damages
- The generation of a heat wave expanding with the shock causes incineration
- The distribution of radiation through Short range and atmospheric fallout causes short term and long term radiation sickness effects
- Electromagnetic shock leads to break-down of communication systems

The mechanical shock



pressure



shock velocity:	v_s
sound speed:	c_s
specific heat:	$\gamma=1.4$
peak pressure:	p
air pressure:	$p_0=15$ psi
wind velocity:	v_w
dynamic pressure:	q

$$v_s = c_s \cdot \sqrt{1+\frac{\gamma+1}{2\cdot\gamma}\cdot\frac{p}{p_0}} = c_s \cdot \sqrt{1+0.86\cdot\frac{p}{p_0}}$$

$$v_w = \frac{c_s \cdot p}{\gamma \cdot p_0}\cdot\left(1+\frac{\gamma+1}{2\cdot\gamma}\cdot\frac{p}{p_0}\right)^{-1/2} = 0.715\cdot\frac{p}{p_0}\cdot\frac{c_s}{\sqrt{1+0.86\cdot p/p_0}}$$

$$q = \frac{p^2}{2\cdot\gamma\cdot p_0+(\gamma-1)\cdot p} = 2.5\cdot\frac{p^2}{7\cdot p_0 + p}$$

Example

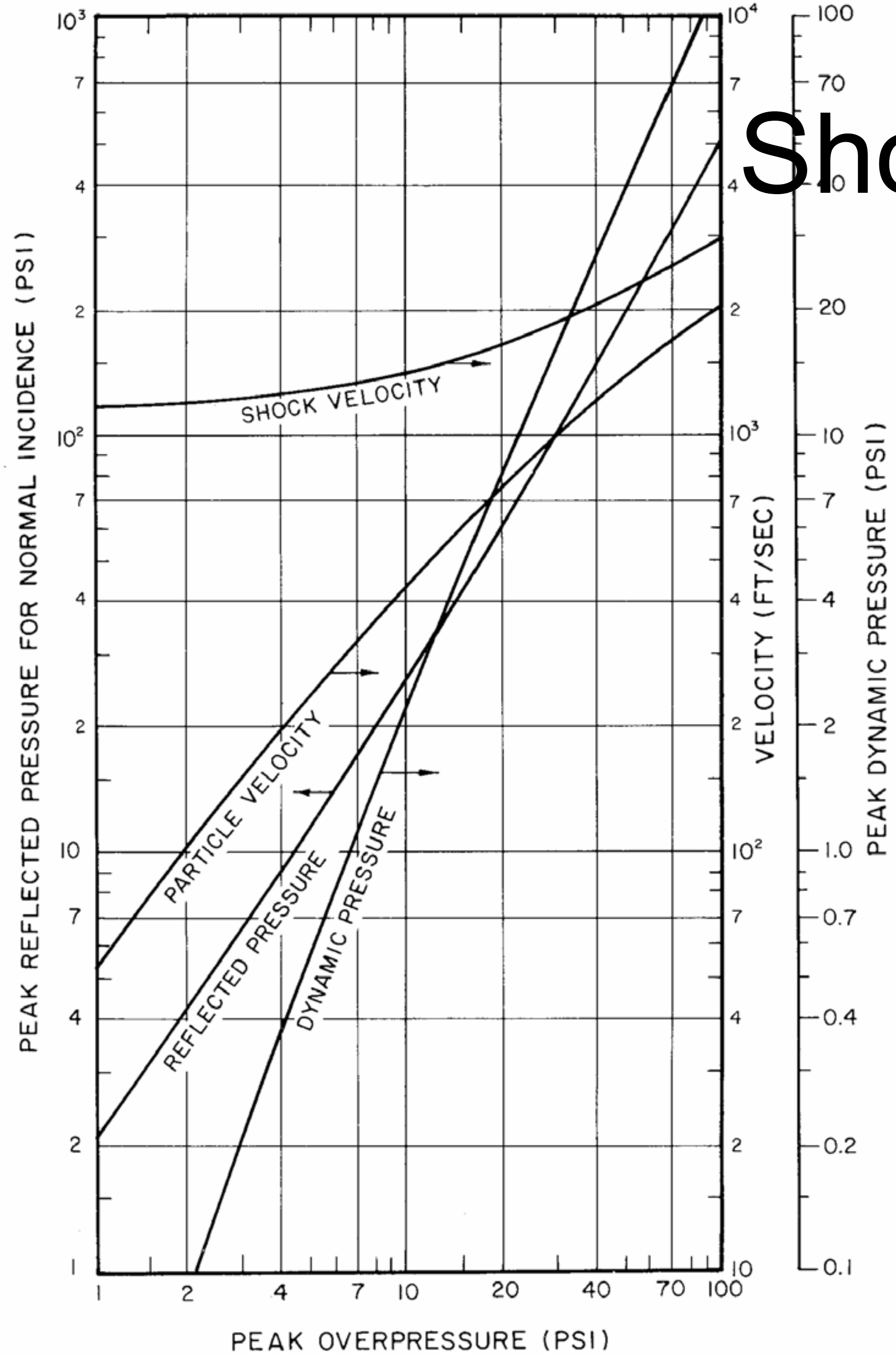
Depending on the peak pressure (atmospheric pressure 15 psi) and the speed of sound (c_s=330 m/s in atmospheric gas) you receive the following values for shock and wind velocity and dynamic pressure

$$v_s = c_s \cdot \sqrt{1 + 0.83 \cdot \frac{p}{p_0}}$$

$$v_w == 0.715 \cdot \frac{p}{p_0} \cdot \frac{c_s}{\sqrt{1 + 0.86 \cdot p/p_0}}$$

$$q = 2.5 \cdot \frac{p^2}{7 \cdot p_0 + p}$$

p	v_s	v_w	q
psi	m/s	m/s	psi
1000	2777	2309	2262
500	1981	1619	1033
300	1552	1240	556
200	1285	999	328
100	946	680	122
50	718	448	40
30	603	321	17
20	537	241	8
10	461	141	2
5	418	78	1
3	400	49	0
2	390	33	0
1	380	17	0



Shock characteristics

Shock on flat surface causes reflection which is expressed by reflected overpressure $p_{r!}$

$$p_r = 2p + (\gamma + 1) \cdot q = 2p \cdot \frac{7p_0 + 4p}{7p_0 + p}$$

$p_r \approx 8p$ for large dynamic pressure

$p_r \approx 2p$ for small dynamic pressure

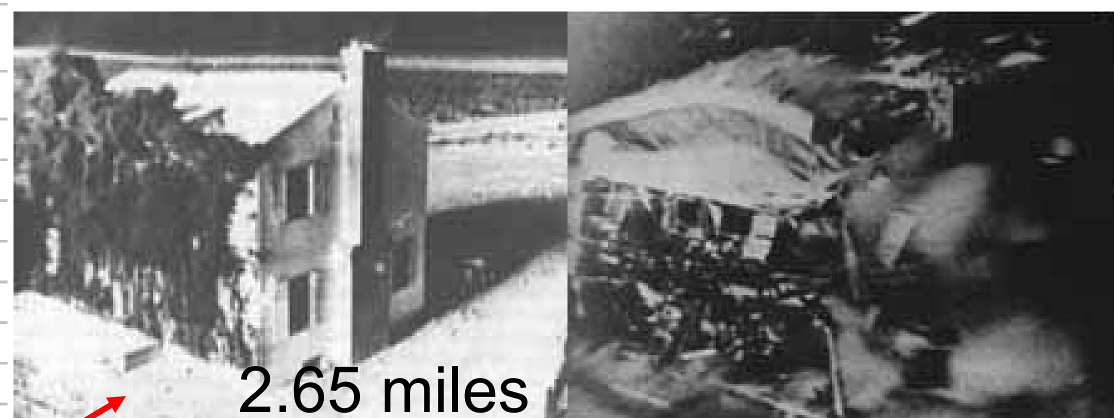
Example shock front against house

example

$$p_r = 2p + (\gamma + 1)\cdot q = 2p \cdot \frac{7p_0 + 4p}{7p_0 + p}$$

250 kT blast Nevada 1953 effect on houses in different distance from center of blast

peak pressure	reflected pressure	
p	p_r	p_r/p
psi	psi	
1000	7430	7
500	3479	7
300	1933	6
200	1187	6
100	493	5
50	197	4
30	100	3
20	59	3
10	25	3
5	11	2
3	7	2
2	4	2



over pressure – wind velocity

over pressure	wind velocity
[psi]	mi/h
200	2078
100	1777
72	1415
50	934
20	502
10	294
5	163
2	70

Even an over pressure of 2 psi generates hurricane like storm conditions!

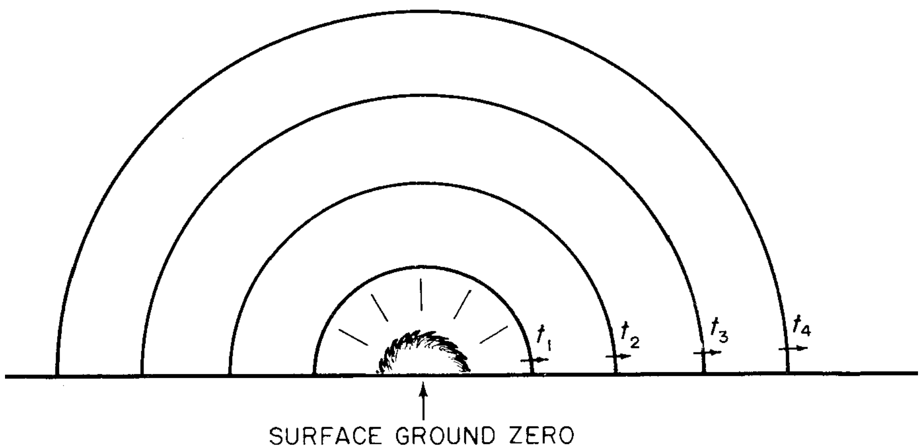
OPERATION DOORSTEP

and

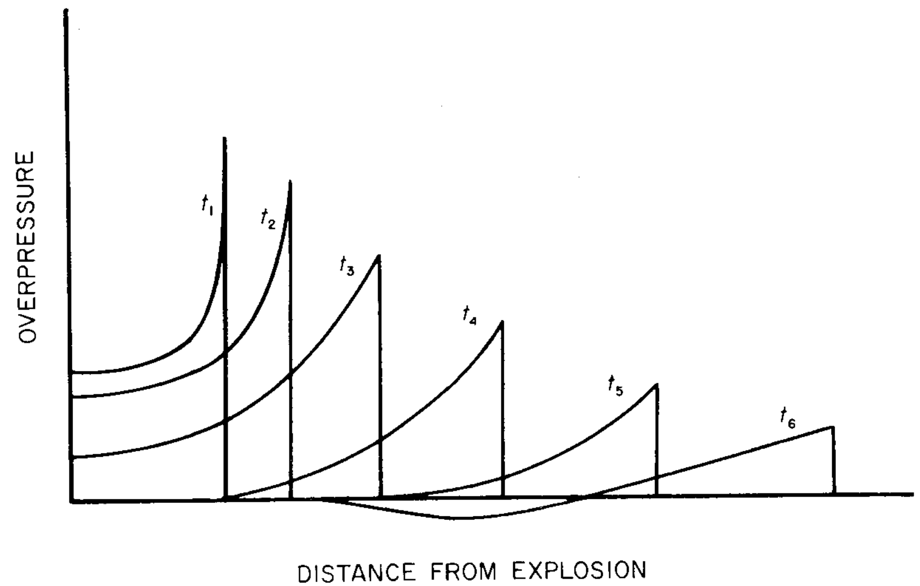
OPERATION CUE

The American Home

Shock expansion



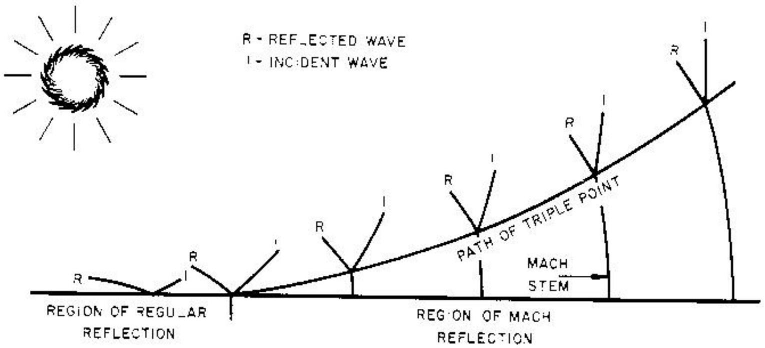
Blast wave from a contact surface burst; incident and reflected waves coincide.



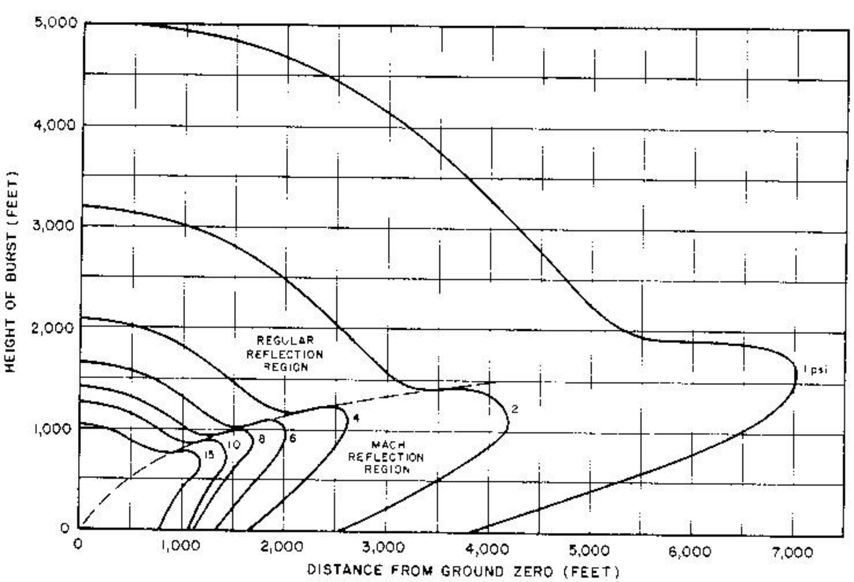
Variation of overpressure in air with distance at successive times.

Shock expands radially from explosion center. Amplitude decreases, but after time t_5 the pressure behind shock front falls below atmospheric pressure, Under-pressure which causes the air to be sucked in.

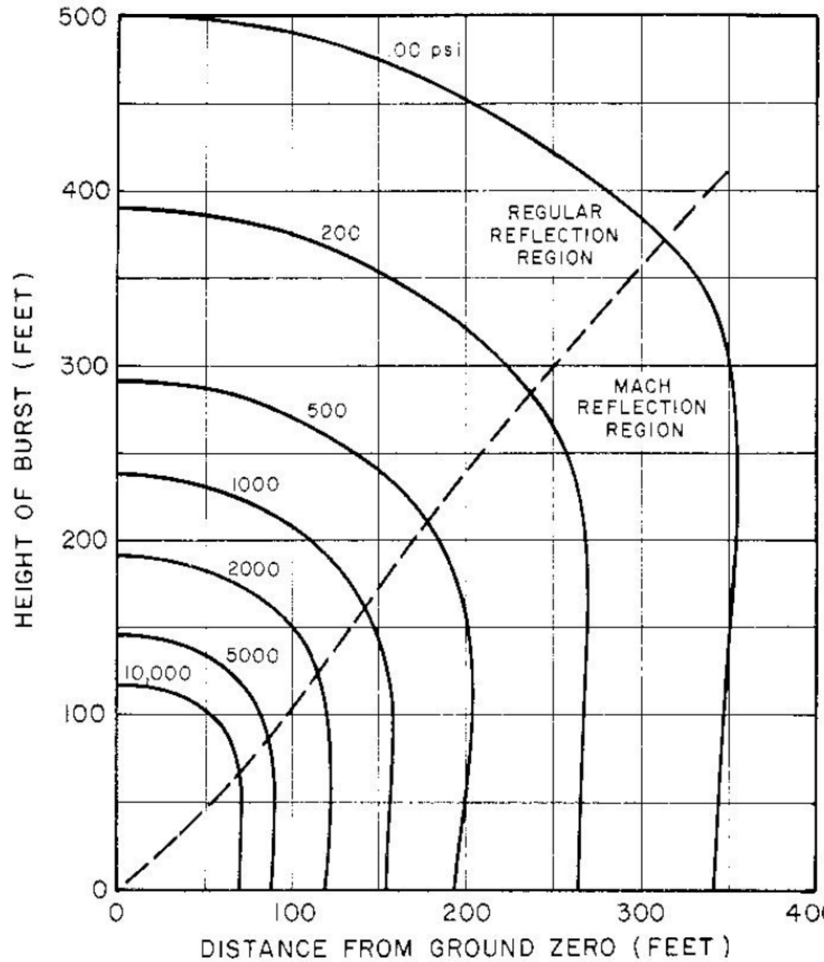
Overpressure and Mach Stem



The original or incident wave and the reflected wave from the ground combine to form a Mach-stem shock wave that has approximately double the overpressure of the original shock wave. The Mach-stem wave propagates horizontally in the figure (actually radially in all directions from the burst point).

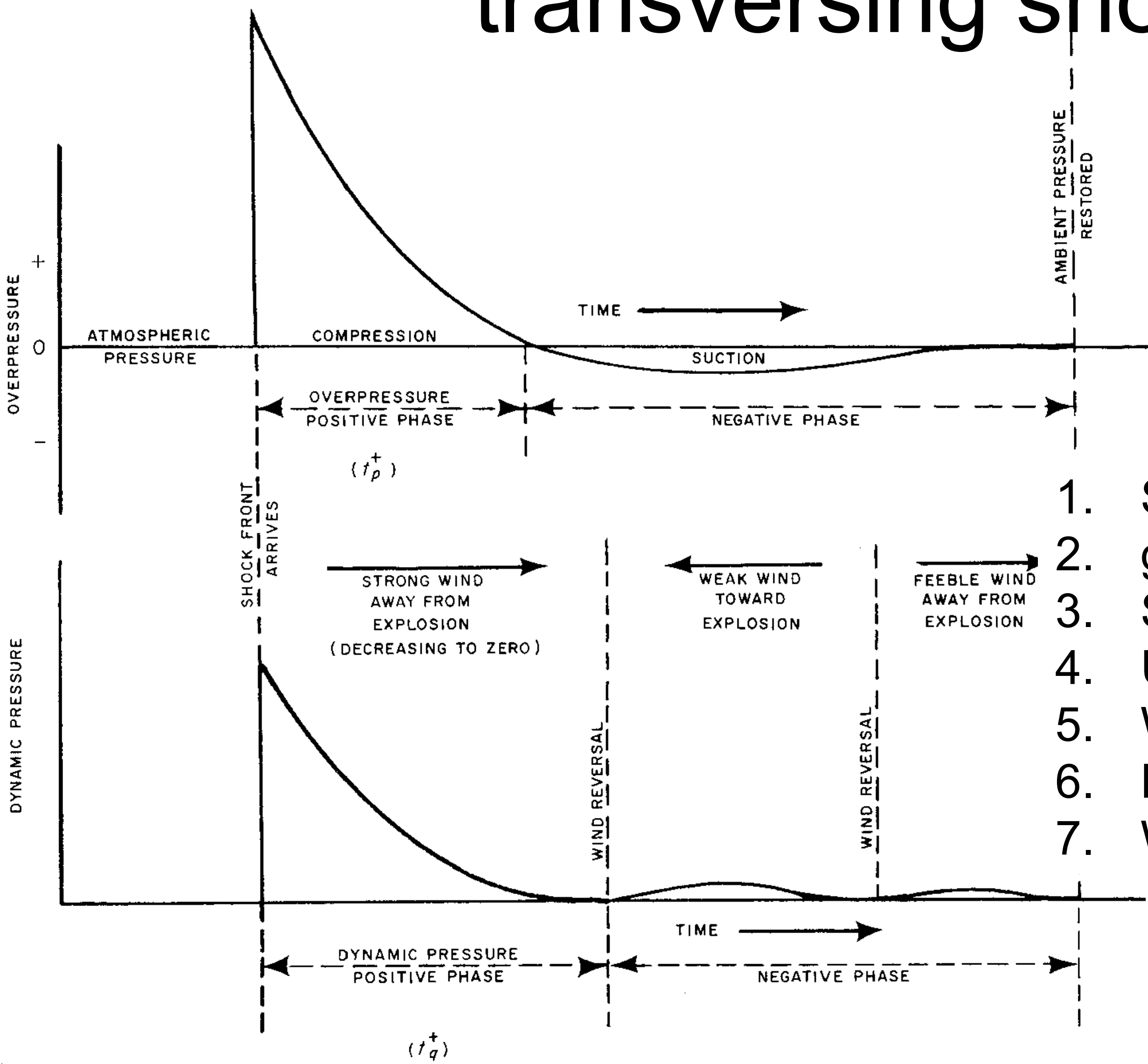


Peak overpressures on the ground for a 1-kiloton burst (low-pressure range). The distance is measured from ground zero.



Peak overpressure on the ground for a 1-kiloton burst (high-pressure range). The figure is similar to Figure 13-4, except that it depicts the overpressure nearer ground zero. The distance is again that from ground zero (or *d* of Figure 13-4). Note that in order to achieve very high overpressures, such as those necessary to destroy a missile silo, the burst must be near the surface.

Pressure conditions with transversing shock



1. Shock hits
2. generates strong wind
3. Shock decreases
4. Underpressure
5. Wind direction changes
6. Normal air pressure
7. Wind calms down

Variation of overpressure and dynamic pressure with time at a fixed location.

Pressure induced wind effects

Scaling laws for blast effects

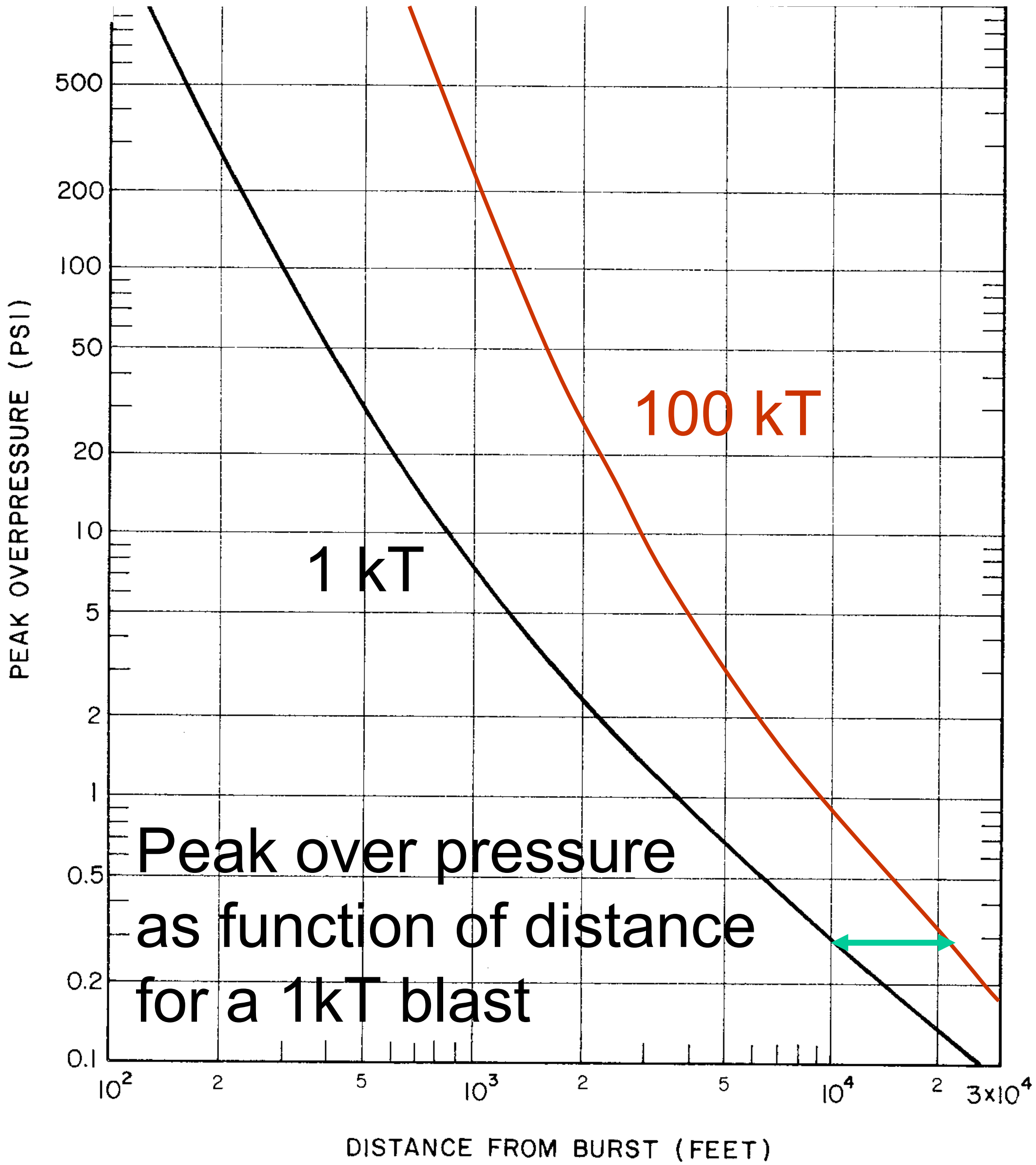
Shock/blast expands over volume $\sim d^3$, the following scaling law can be applied for estimating distance effects between different blast strengths

$$\frac{W}{W_0} = \left(\frac{d}{d_0}\right)^3 \Rightarrow d = d_0 \left(\frac{W}{W_0}\right)^{1/3}$$

Normalized to a standard 1kT blast the following expression can be applied:

$$d = d_1 \cdot W^{1/3}$$

Distance Effects

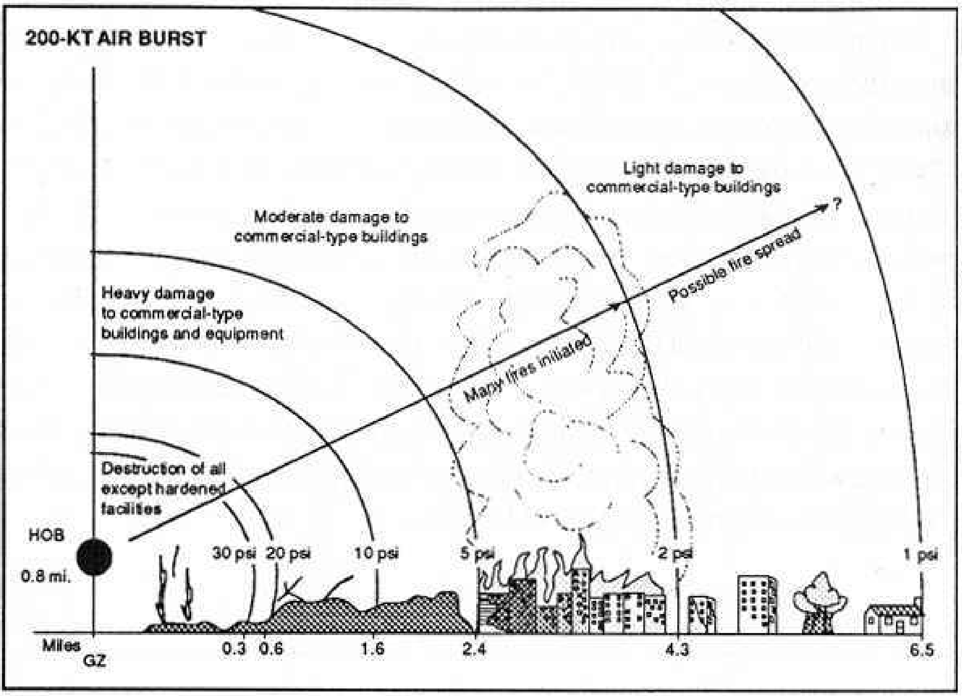


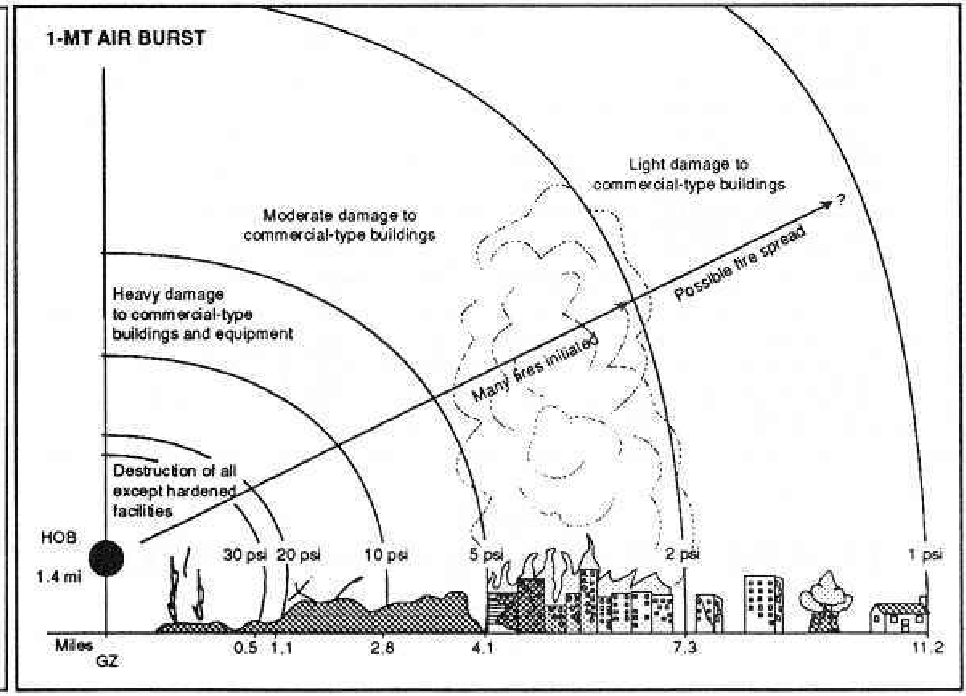
Scaling for blast intensities

$$d = d_1 \cdot W^{1/3}$$

e.g. the effect which occurs for a 1 kT blast at distance d_1 occurs for a 100kT blast at distance d. d_1=10,000ft ⇨ d=24,662ft.

Distance effects of airburst





$$d = d_0 \cdot \left(\frac{W}{W_0}\right)^{1/3} = d_0 \cdot \left(\frac{1000}{200}\right)^{1/3} = 1.7 \cdot d_0$$

$$= d_0 \cdot \left(\frac{500}{200}\right)^{1/3} = 1.35 \cdot d_0$$

damage comparison for a 1000 kT and a 500 kT bomb using the scaling law with respect to 200 kT bomb

Scaling in Altitude

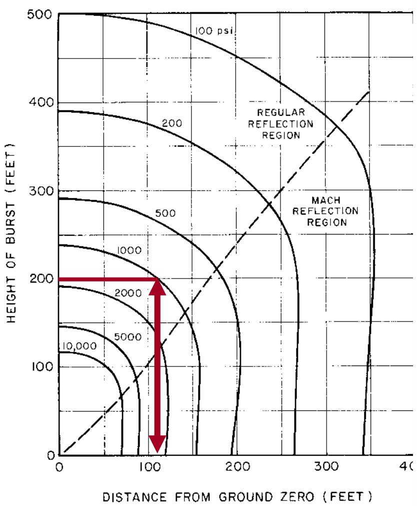
$$\frac{h}{h_1} = \left(\frac{W}{W_1}\right)^{1/3} = \frac{d}{d_1}$$

often scaled to W_1 = 1 kT

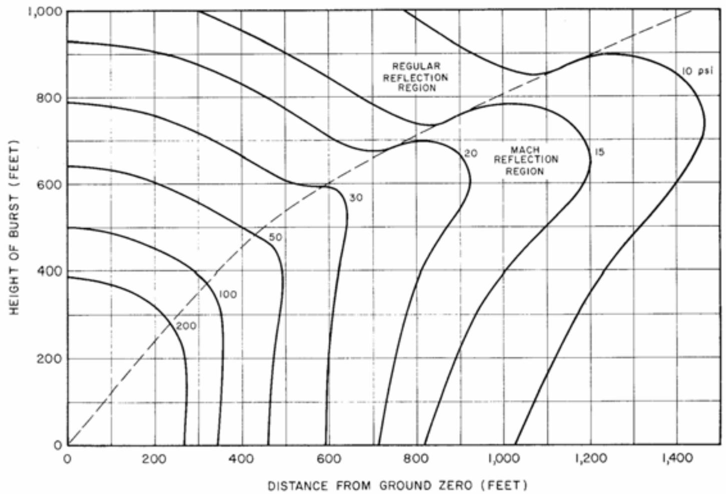
$$\frac{h}{h_1} = W^{1/3} = \frac{d}{d_1}$$

Similar scaling relation for altitude dependence of blast effects. For altitudes less than 5000 ft (1700 m) normal atmospheric conditions can be assumed. For higher altitude effects changes, altitude dependence of air pressure and sound speed need to be taken into account.

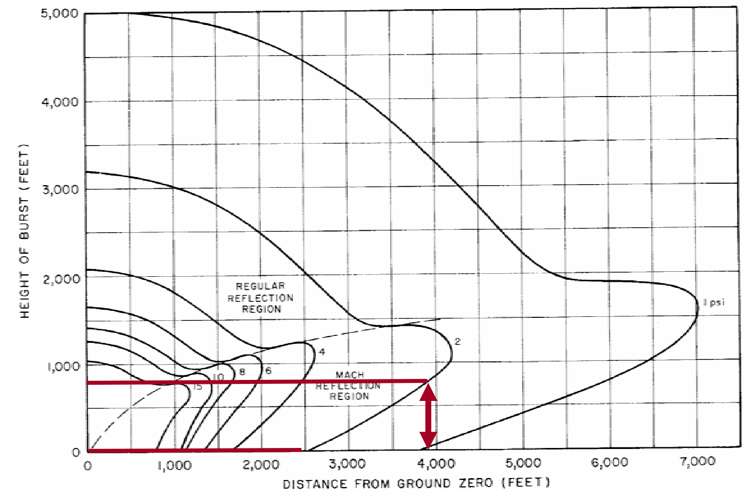
Peak overpressure in height & distance



Peak overpressures on the ground for a 1-kiloton burst (high-pressure rang



Peak overpressures on the ground for a 1-kiloton burst (intermediate-pressure range).



Peak overpressures on the ground for 1-kiloton burst (low-pressure range).

Suppose you have 80 kT bomb at 860 ft height, what is the distance to which 1000psi overpressure extends? Normalization: W_1=1kT

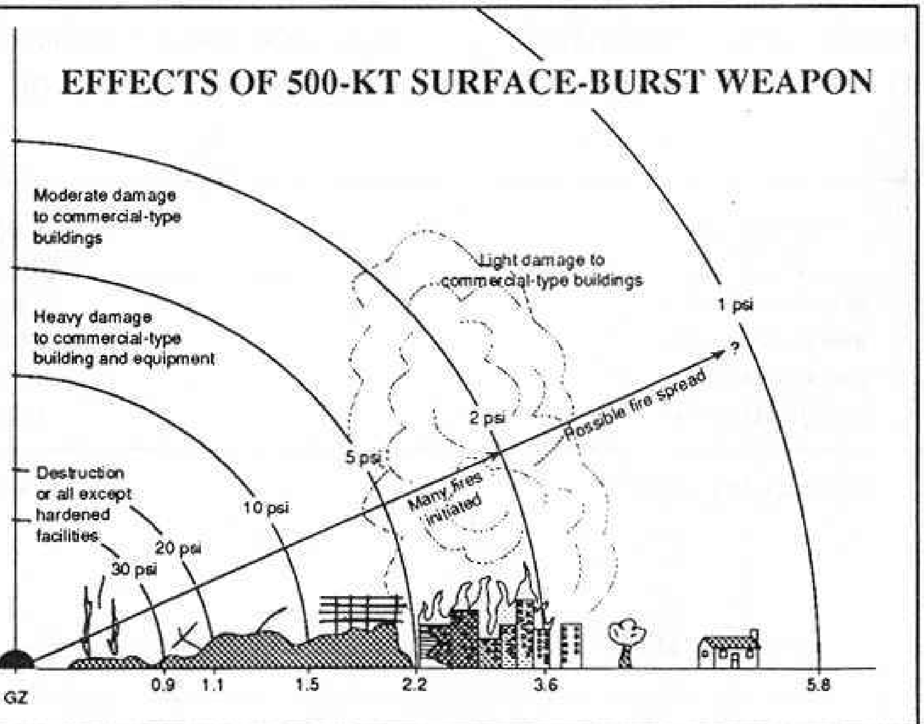
Corresponding height for 1kT burst (or scaled height)

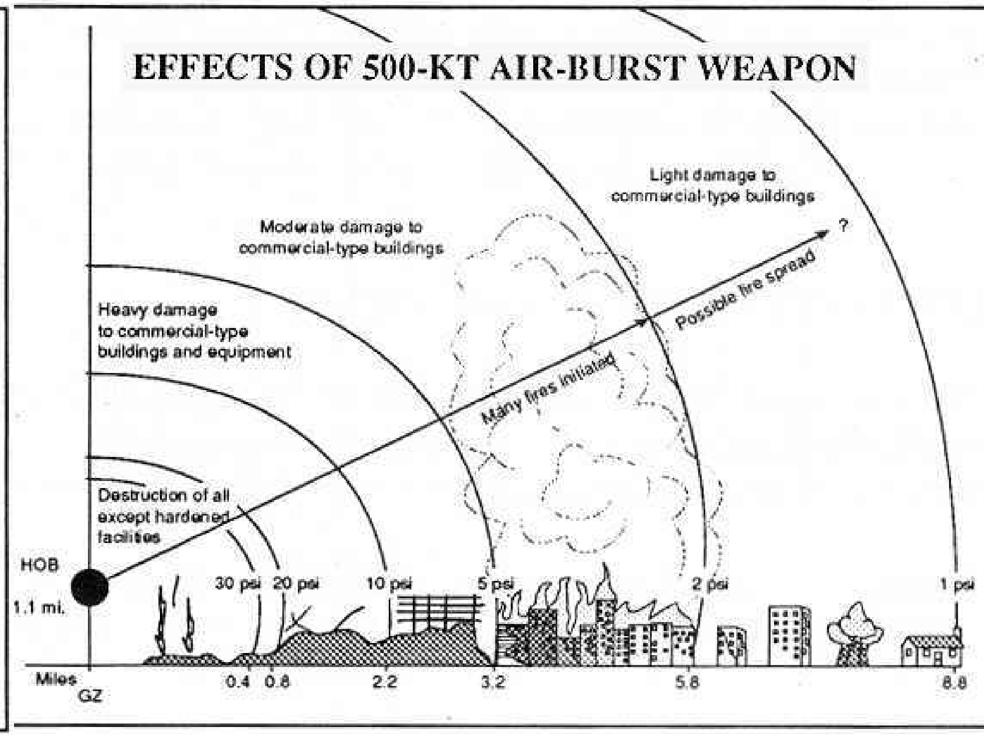
$$h_1 = \frac{h}{W^{1/3}} = \frac{860}{80^{1/3}} = 200\,ft$$

Distance of 1000 psi overpressure

$$d = d_1 \cdot W^{1/3} = 110 \cdot 80^{1/3} = 475\,ft$$

Surface burst versus airburst

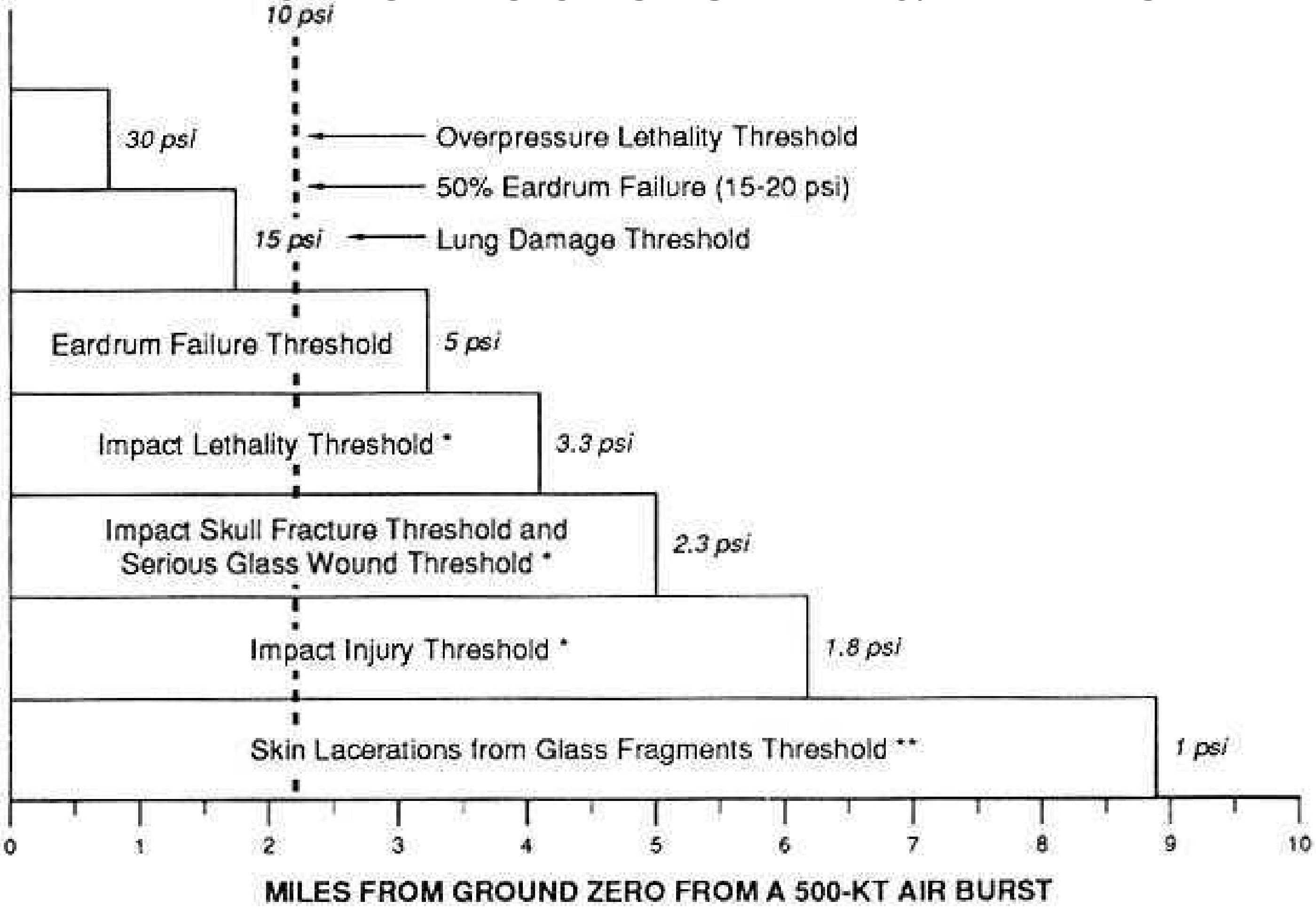




Suppose you have 500 kT bomb at 1.1 mile height, what is the distance to which 2 psi overpressure extends and compare with ground zero detonation. Scaled height for 1 kT bomb; $h_1 = h/W^{1/3} = 0.14$ miles ≈ 765 ft. This corresponds to $d_1 = 3800$ ft = 0.69 miles. The distance for the 2 psi overpressure on the ground from the 500 kT blast would be $d = d_1 \cdot W^{1/3} = 0.69 \cdot 500^{1/3} =$ **5.5 miles**.

Surface burst: d_1=2500 ft=0.45 miles, $d = d_1 \cdot W^{1/3} = 0.45 \cdot 500^{1/3} =$ **3.6 miles.**

Blast effects on humans

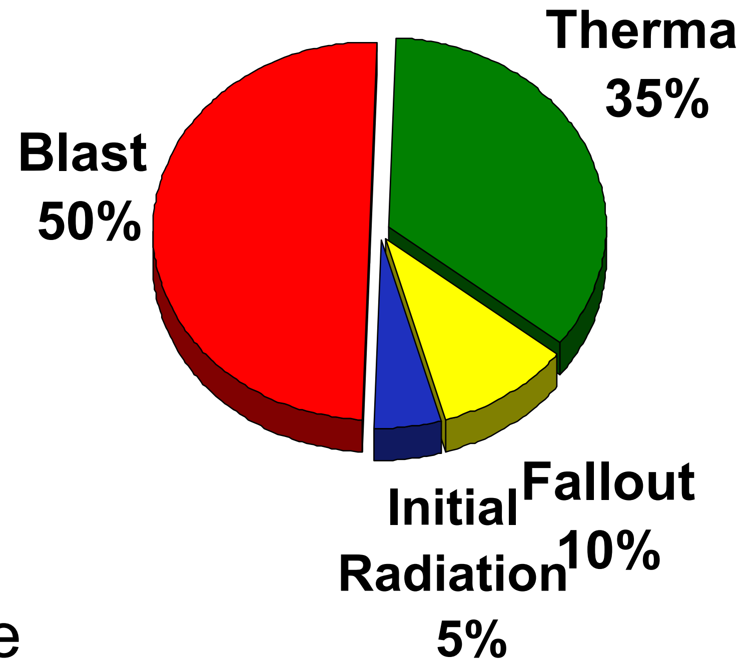


* *For impact injury or death to occur at stated overpressure, the body must be thrown at least 10 feet before impact. Otherwise, a higher overpressure is required to achieve necessary velocity.*

** *Glass fragments must also travel at least 10 feet.*

Thermal effects

Approximately 35 percent of the energy from a nuclear explosion is an intense burst of thermal radiation, i.e., heat. Thermal effects are mainly due to originated heat from blast which expands with wind velocity and incinerates everything within expansion radius. The thermal radiation from a nuclear explosion can directly ignite kindling materials. Ignitable materials outside the house, such as leaves, are not surrounded by enough combustible material to generate a self-sustaining fire. Fires more likely to spread are those caused by thermal radiation passing through windows to ignite beds and overstuffed furniture inside houses.



Thermal Energy Release

For a fireball with radius *r* the heat emitting surface is:

$$\boxed{S = 4\pi \cdot r^2}$$

Total energy emitted per cm^2 and second is described by the Stefan Boltzmann law

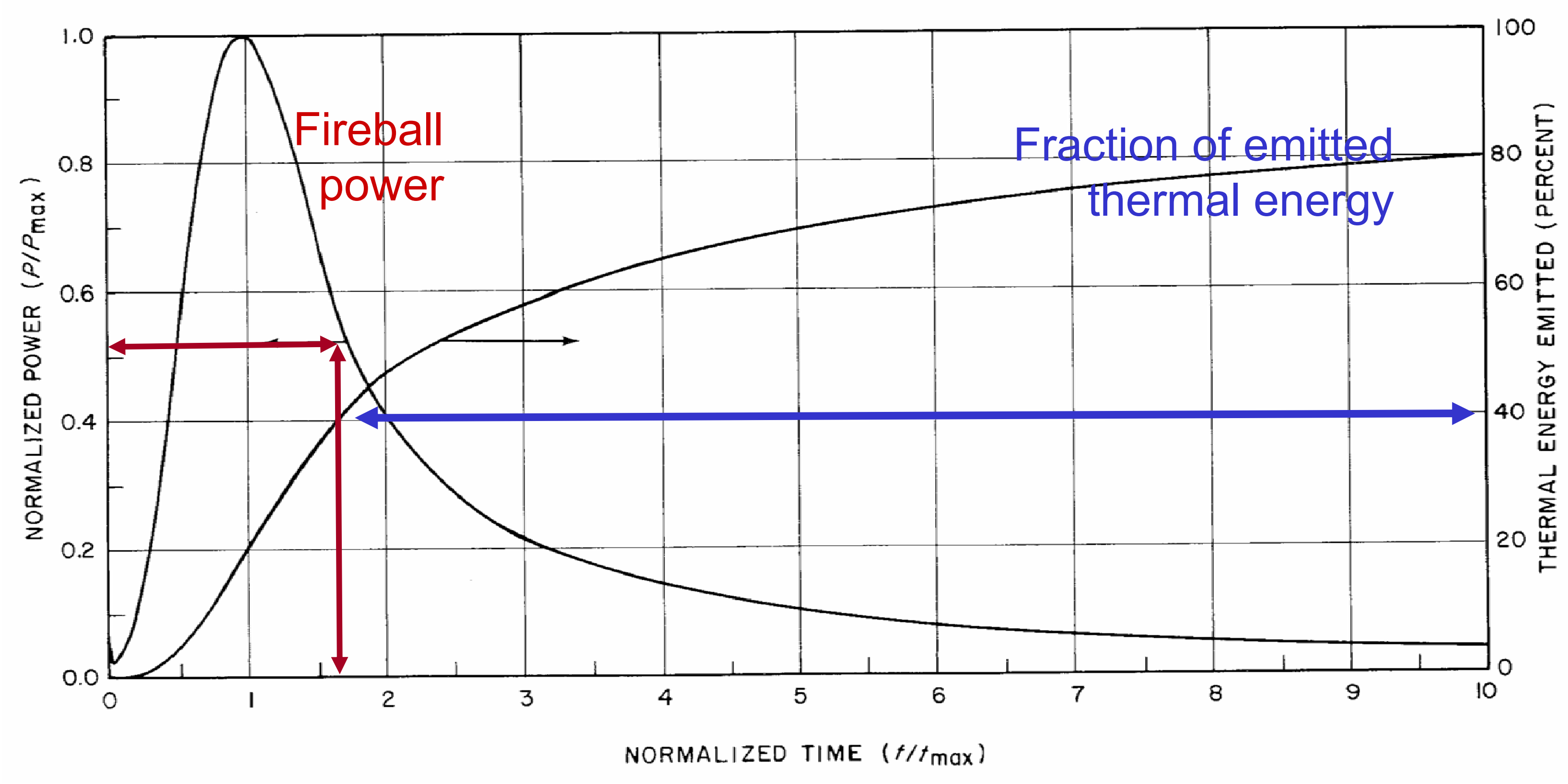
$$\boxed{J = \sigma \cdot T^4; \quad \sigma = 1.36 \cdot 10^{-12}\ cal\, cm^{-2} s^{-1} deg^{-4}}$$

Total thermal energy emission from fireball is therefore:

$$\boxed{P = S \cdot J = 4\pi \cdot \sigma \cdot T_4 \cdot r^2 = 1.71 \cdot 10^{-7} \cdot T^4 \cdot r^2\ cal / sec}$$

With radius *r* in units m and temperature *T* in Kelvin

The thermal power of the fireball changes with time. Thermal energy release should be expressed in terms of maximum power P_{max} (scaled power) and in terms of scaled time t_{max} which corresponds of time of the maximum thermal energy release from the fireball.



For air bursts below 15,000 ft altitude the maximum power P_{max} & the maximum time t_{max} are related to the bomb yield W (in kT)

$$\boxed{\begin{aligned} P_{\max} &\approx 3.18 \cdot W^{0.56} \quad kT/\sec \\ \mathrm{t}_{\max} &\approx 0.0417 \cdot W^{0.44} \quad \sec \end{aligned}}$$

e.g. for a 500 kT burst in 5000 ft altitude:

$$\boxed{\begin{aligned} P_{\max} &\approx 3.18 \cdot 500^{0.56} = 103\, kT/\sec \\ \mathrm{t}_{\max} &\approx 0.0417 \cdot 500^{0.44} = 0.64 \sec \end{aligned}}$$

According to the scaling laws expressed in the figure, total power and fraction of heat release can be calculated for any time; e.g. the total amount of thermal energy emitted at t=1sec is:

$$\boxed{\begin{gathered} \frac{t}{t_{\max}} = \frac{1}{0.64} = 1.56; \quad \frac{P}{P_{\max}} = 0.59 \quad (see\ figure); \\ P = 0.59 \cdot P_{\max} = 0.59 \cdot 103 = 60.8\, kT/\sec = 60.8 \cdot 10^{12}\, cal/\sec \end{gathered}}$$

Fraction of thermal energy released at 1 s is 40%!

Firestorms

Fires can result from combustion of dry, flammable debris set loose by the blast or from electrical short circuits, broken gas lines, etc. These fires can combine to form as terrible firestorm similar to those accompanying large forest fires. The intense heat of the fire causes a strong updraft, producing strong inward drawn winds in which fan the flame, take away oxygen so it is difficult to breath, and destroy everything in their path (Chimney Effect).

The expansion of firestorms

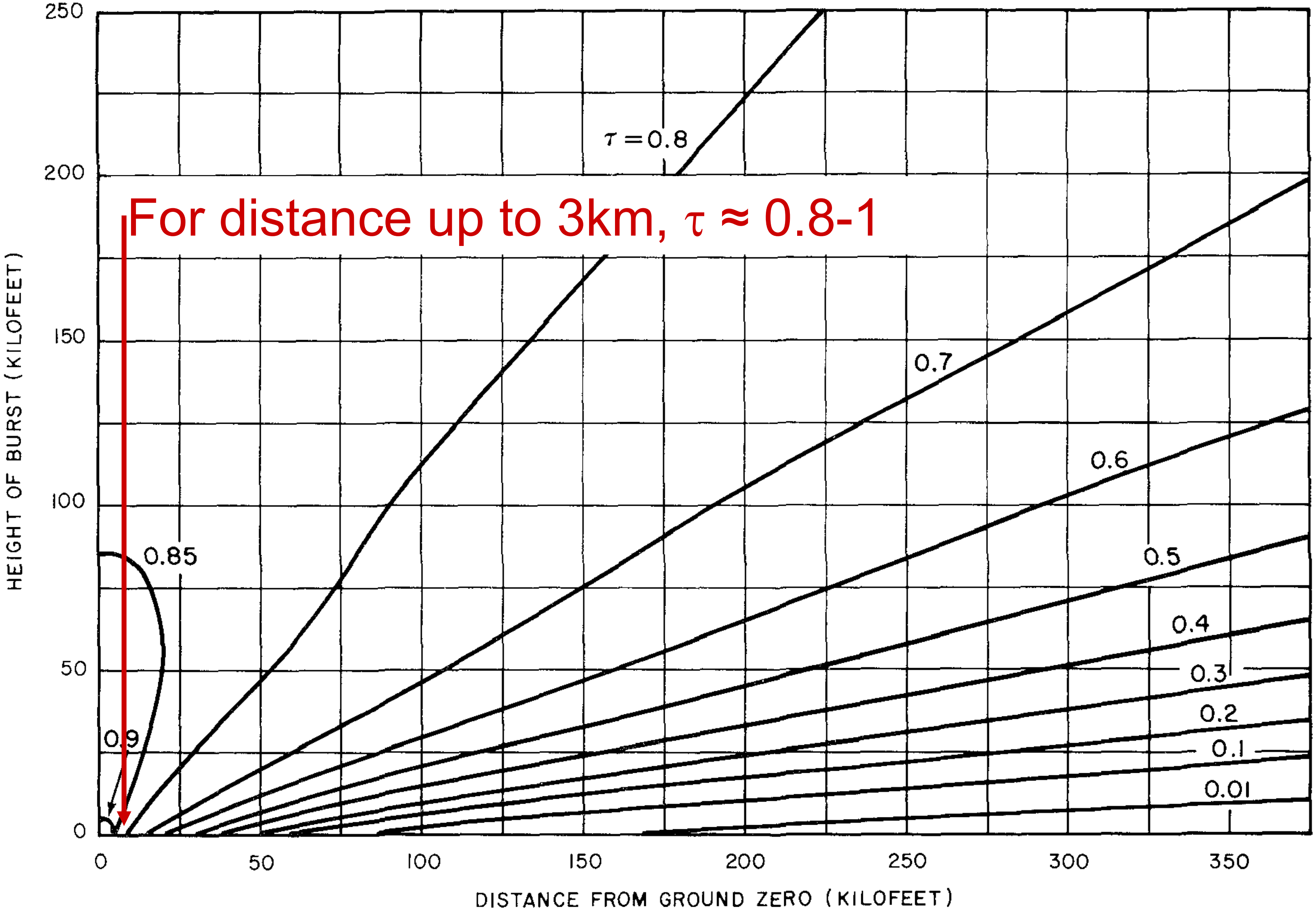
Different scaling laws apply for calculating the heat and incinerating effects from bomb yield. Fire advances by wind driven heat propagation. In a uniform atmosphere without turbulent or convective processes the expansion would follow an exponential law with the radiation absorption parameter κ. The heat exposure at distance d would be:

$$Q = \frac{W_{therm}}{4\pi \cdot d^2} \cdot e^{-\kappa \cdot d}$$

For turbulent firestorms empirical approximations are used to describe transmittance of heat in terms of the transmittance factor τ (empirical factor for visibility) and ***f*** the thermal heat fraction of total energy release (*f* ≈ 0.35-0.42 depending on altitude).

$$Q = \frac{W_{therm} \cdot \tau}{4\pi \cdot d^2} = \frac{f \cdot W \cdot \tau}{4\pi \cdot d^2} = 10^{12} \cdot \frac{f \cdot W \cdot \tau}{4\pi \cdot d^2} \, cal / cm^2$$

Transmittance



Transmittance, τ, to a target on the ground on a typical clear day (visibility = 12 miles).

Effects of thermal radiation on materials

Heat exposure in bright sunlight: 2 cal/cm^2

White paper ignites at ~ 5 cal/cm^2, (magnifying glass)
Fabric ignites at ~20-40 cal/cm^2 depending on color & material

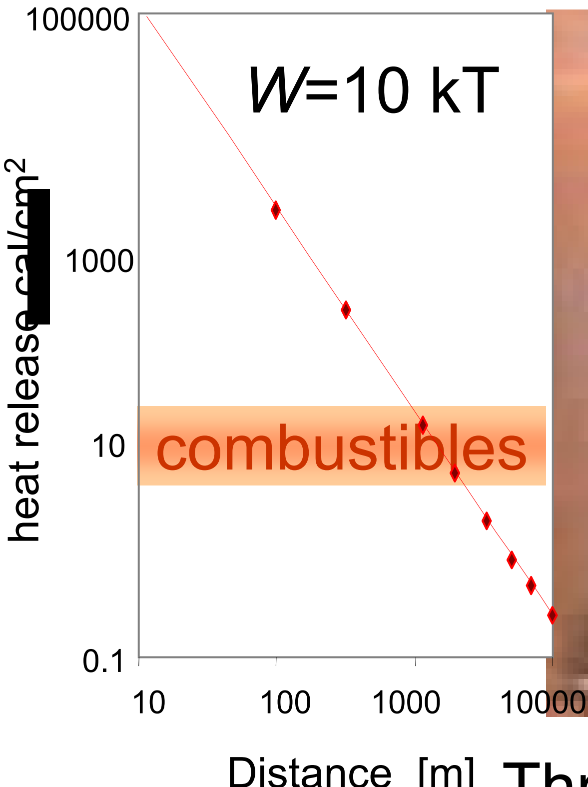
1st degree burn ~ 3 cal/cm^2 (sunburn)
2nd degree burn ~5 cal/cm^2 (skin loss, no scars, >25% body ⌗ hospital)
3rd degree burn ~8 cal/cm^2 (destroy skin nerves, scarring,
no cell regeneration; >50% ⌗ fatal)

In the case of bomb explosions, the released thermal radiation depends on the bomb yield W and also the heat exposure depends on bomb yield.

Ignition of combustibles (W=10 kT)

$$Q = 10^{12}\cdot\frac{f\cdot W\cdot\tau}{4\pi\cdot d^2} = \frac{8\cdot 10^8\cdot f\cdot W\cdot\tau}{d[cm]^2} = \frac{3.07\cdot f\cdot W\cdot\tau}{d[miles]^2}\left[\frac{cal}{cm^2}\right]$$

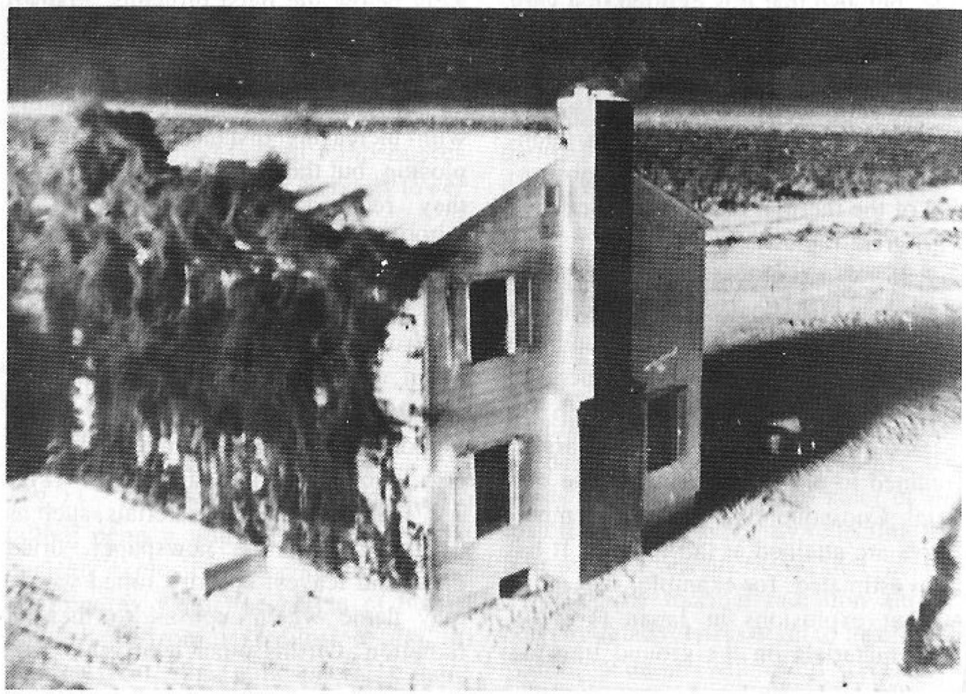
$f \approx 0.35$, $\tau \approx 1$ (for close distances)



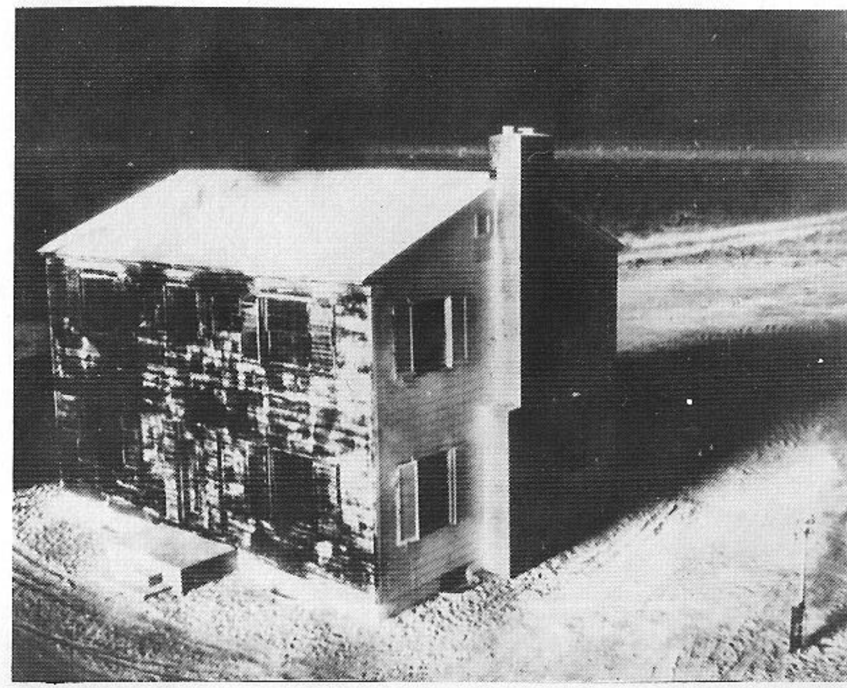
Threshold ignition for combustibles ≳15 cal/cm²
⌗ Ignition of clothes within radius of 2000 m.

Ignition conditions

$$Q = \frac{3.07 \cdot f \cdot W \cdot \tau}{d\,[miles]^2}\left[\frac{cal}{cm^2}\right] = \frac{3.07 \cdot 0.35 \cdot 200[kT] \cdot 0.8}{2.65^2} \approx 25\left[\frac{cal}{cm^2}\right]$$

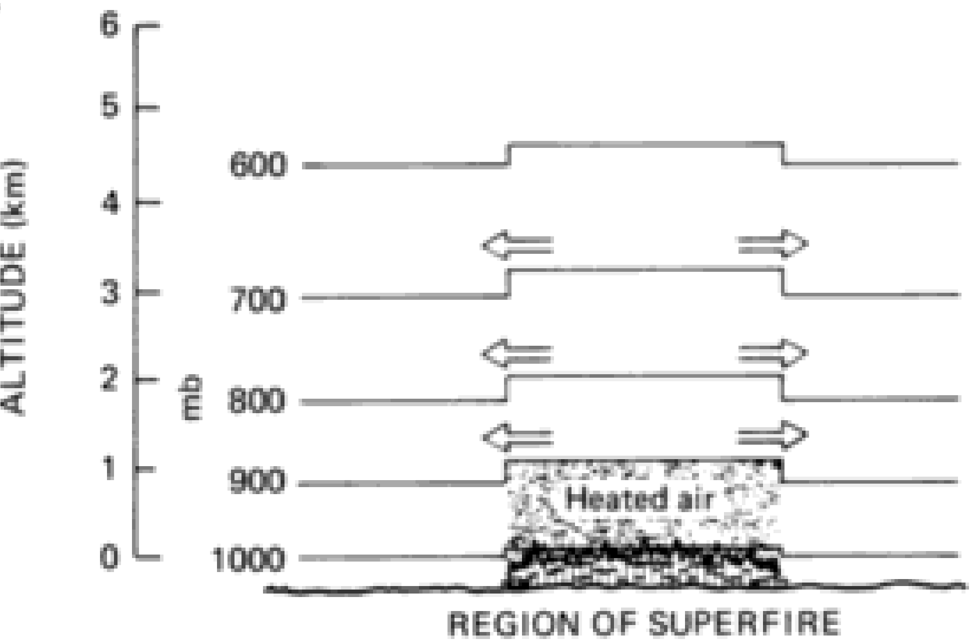


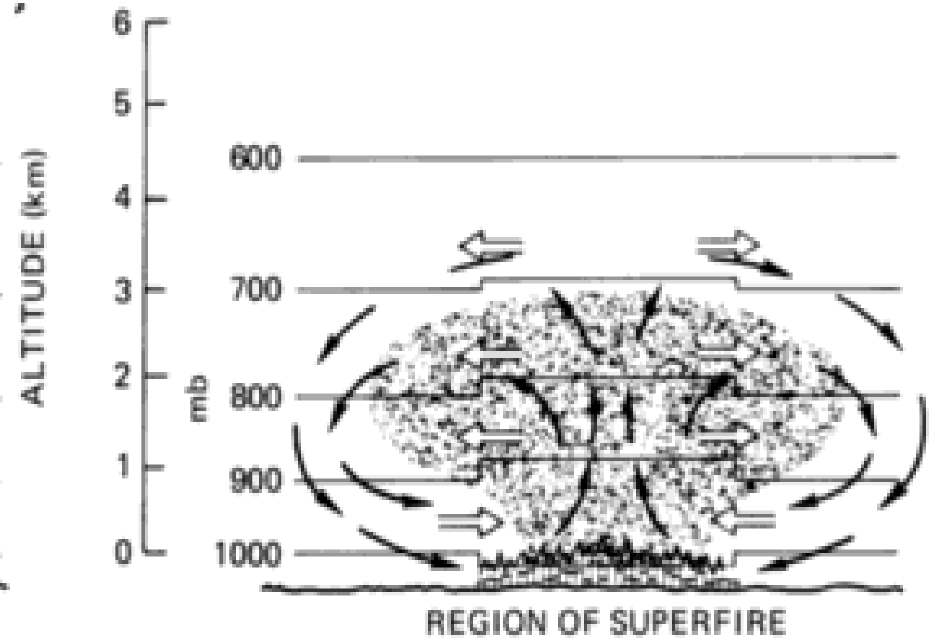
Thermal effects on wood-frame house 1 second after the explosion (~25 cal/cm²) ignition of paint .



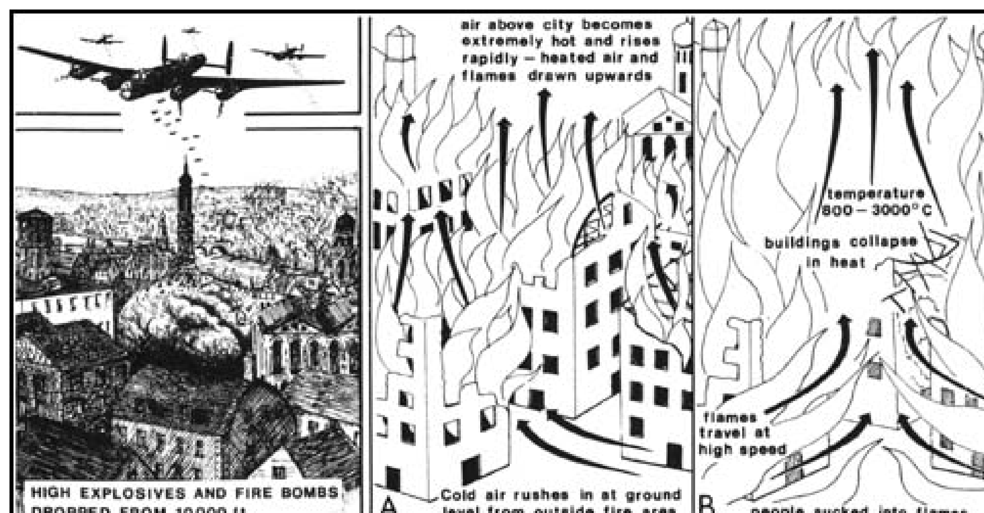
Thermal effects on wood-frame house about ¾ second later. No ignition of the wooden structure.

Fire expansion





Fire expansion is driven by shock driven winds which develop rapidly turbulences due to temperature Differences. Fire spreads with rapid Speed, leaving no chance to escape.



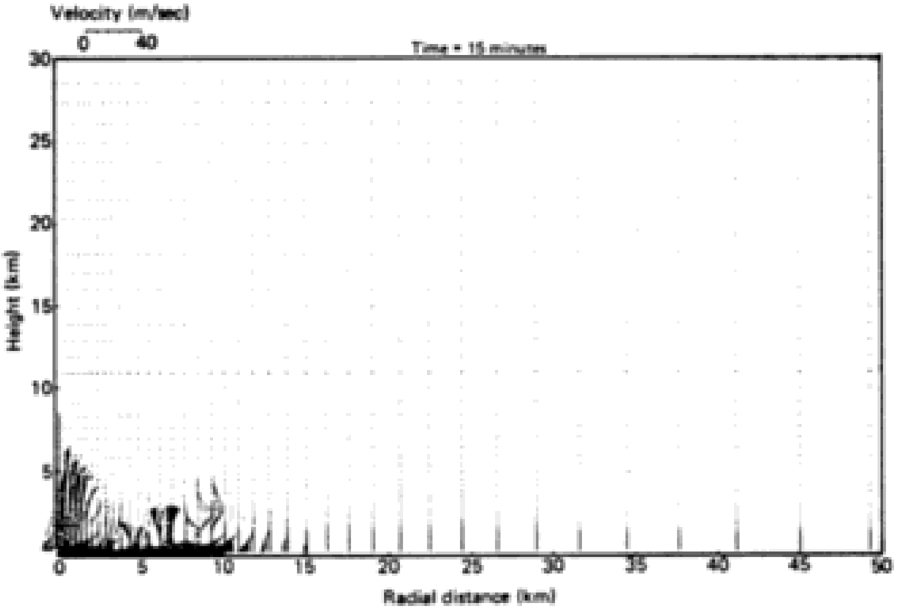


FIGURE 11 Velocity vectors at 15 minutes after the start of a 10-km radius fire.

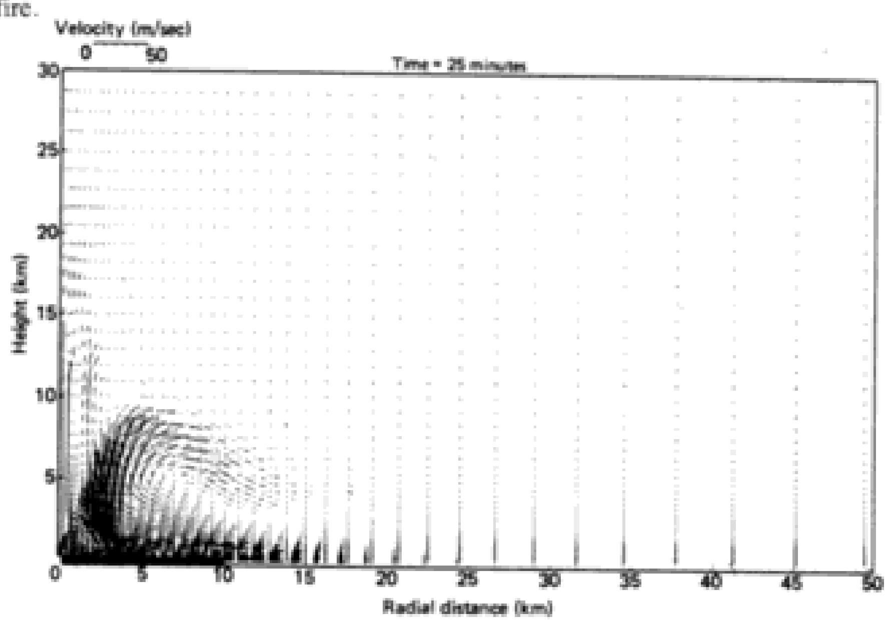


FIGURE 12 Velocity vectors at 25 minutes after the start of a 10-km radius fire.

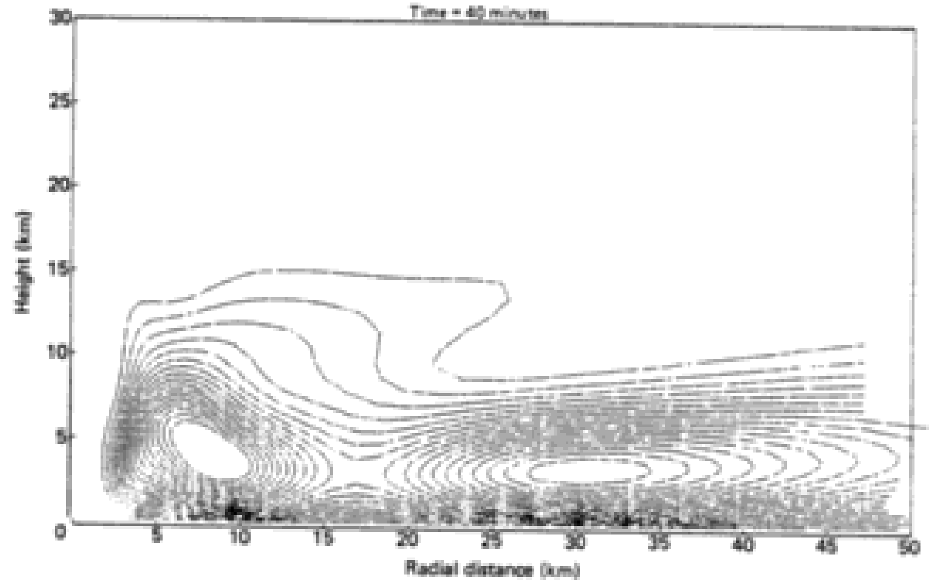


FIGURE 13 Stream lines in atmospheric circulation generated by a 10-km radius fire 40 minutes after ignition.

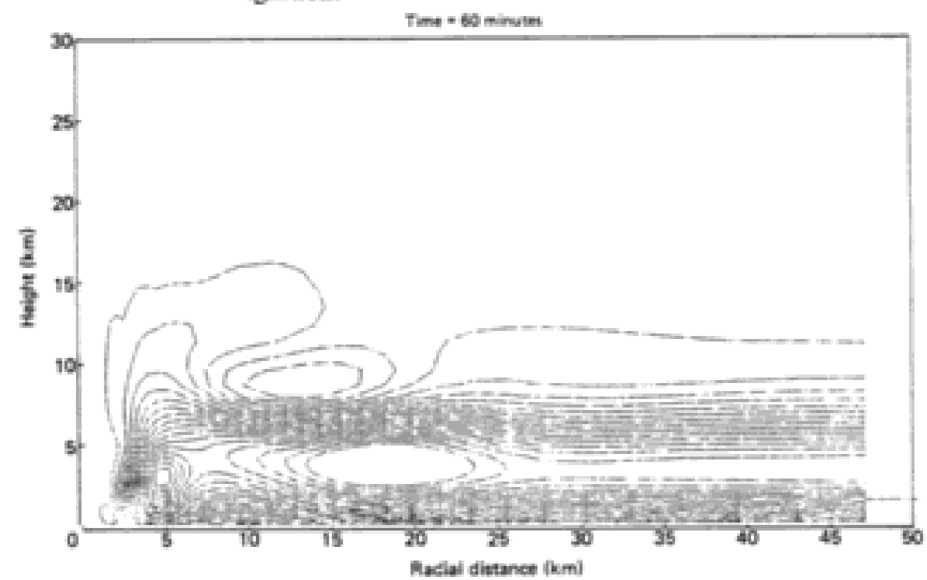
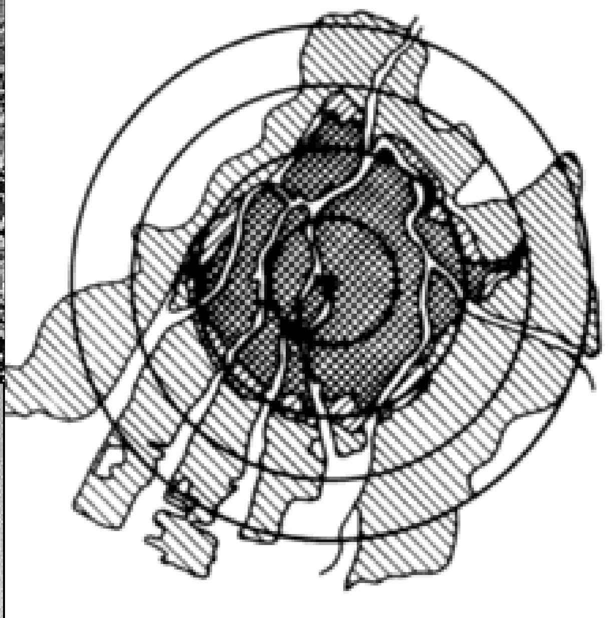


FIGURE 14 Stream lines in atmospheric circulation created by a 10-km radius fire 1 hour after ignition.


HIROSHIMA - PHOTO SUMMARY
PRE-ATTACK MOSAIC
(UNCONTROLLED)
HIROSHIMA
PHOTOS OF 13 APRIL 1945
0
2000
4000
1000
3000
5000
FEET
SECRET
SECRET


HIROSHIMA - PHOTO SUMMARY
POST-ATTACK MOSAIC
(UNCONTROLLED)
HIROSHIMA
PHOTOS OF 11 AUGUST 1945
0
2000
4000
1000
3000
5000
FEET
SECRET
SECRET

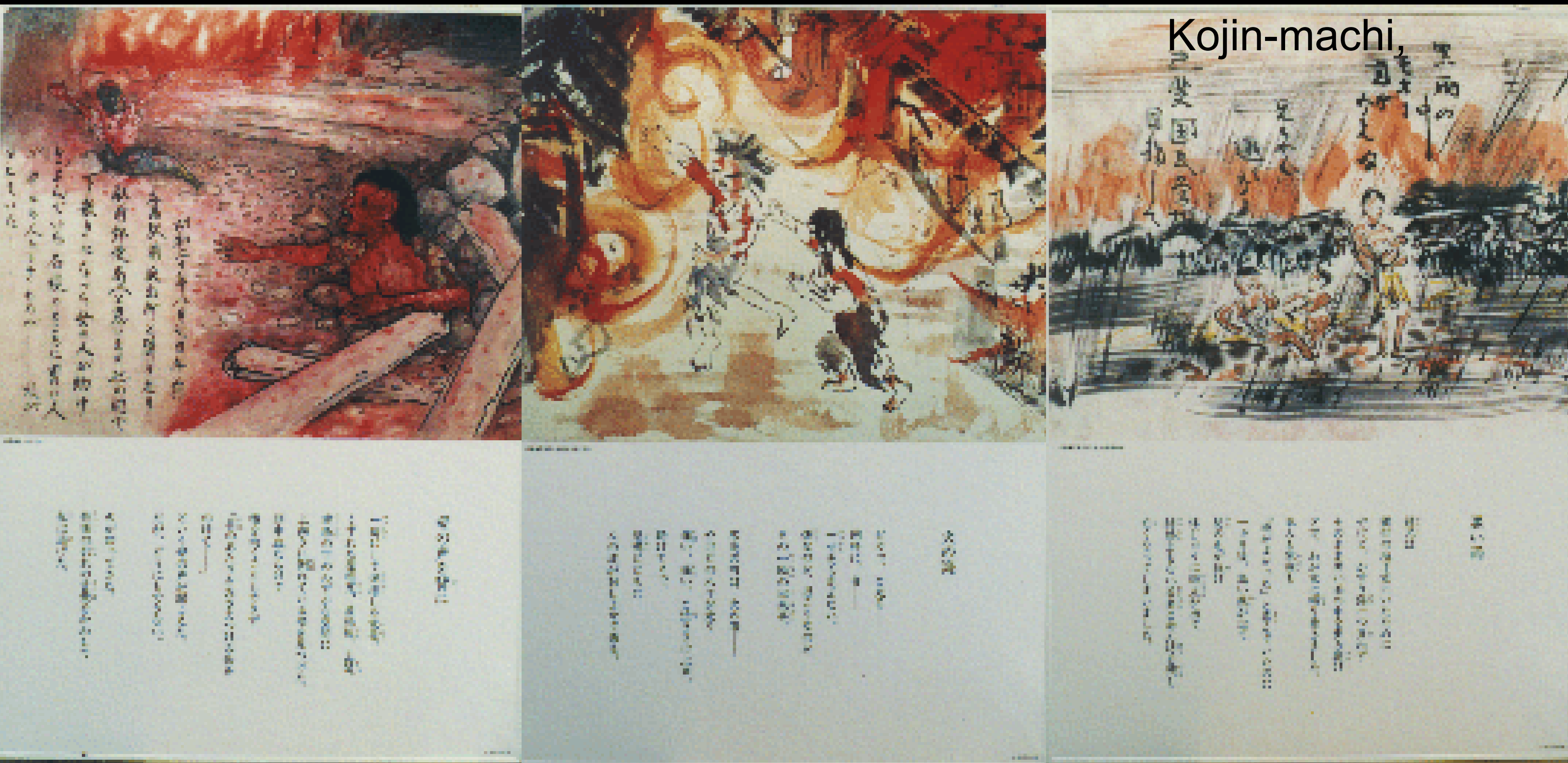
Hiroshima



Hiroshima Victims

Eyewitnesses

A bright flash and explosion at the same time; I could not see an inch ahead Is it smoke or dust? It all happened in a moment Hiroshima was engulfed in a sea of flames. Those who got burns were fleeting here and there, crying in pain “Help!" With screams, a wave of people come rushing toward me.



Burn wounds

Peeled skin was dangling like seaweed from their arms
Red flesh exposed
People were staggering with vacant eyes
Extending their arms forward
Like ghosts
Suddenly they fell, stumbling over something
Never to get up again

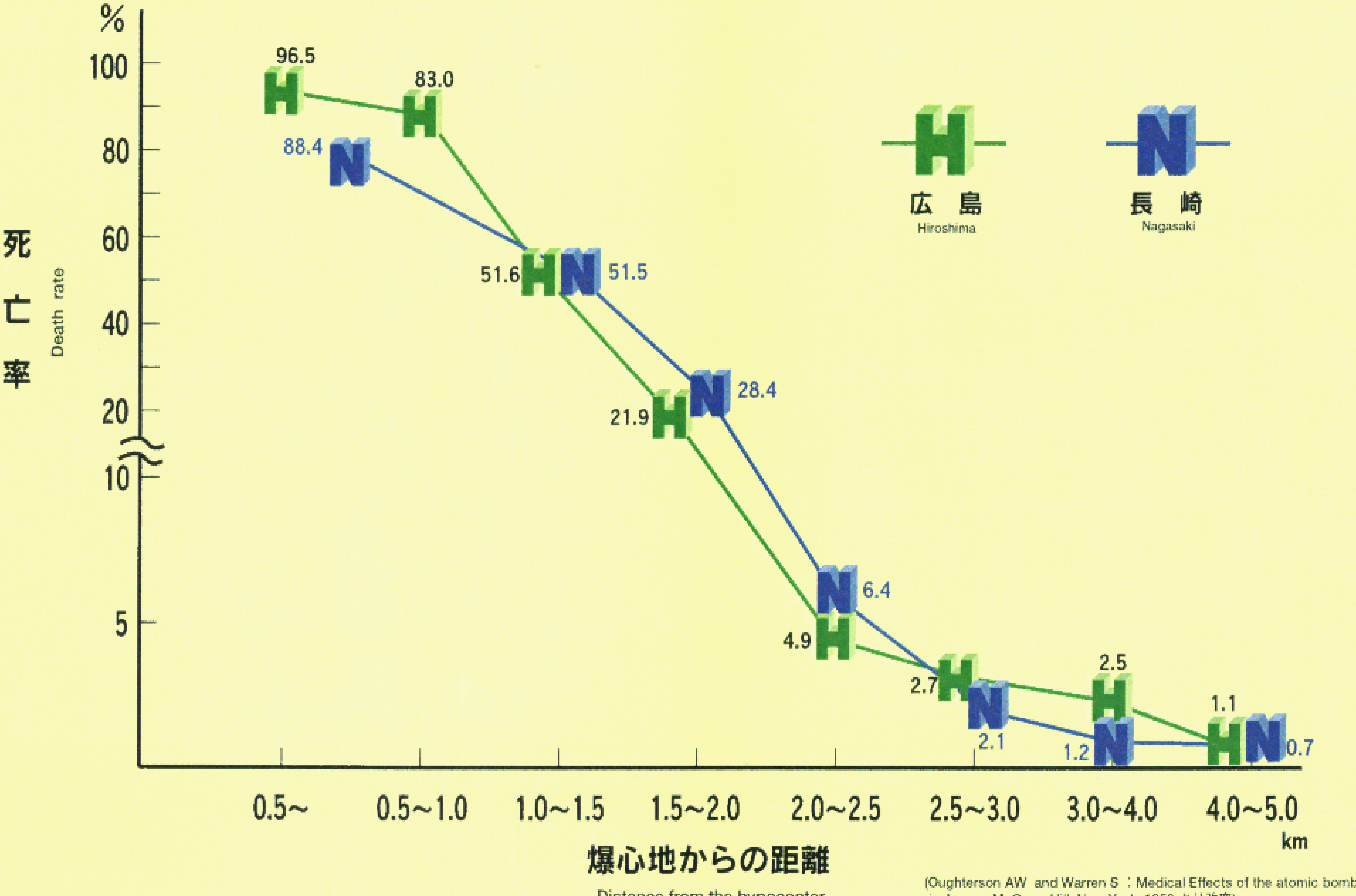
People burning

Victims

Victims

原爆による死亡率

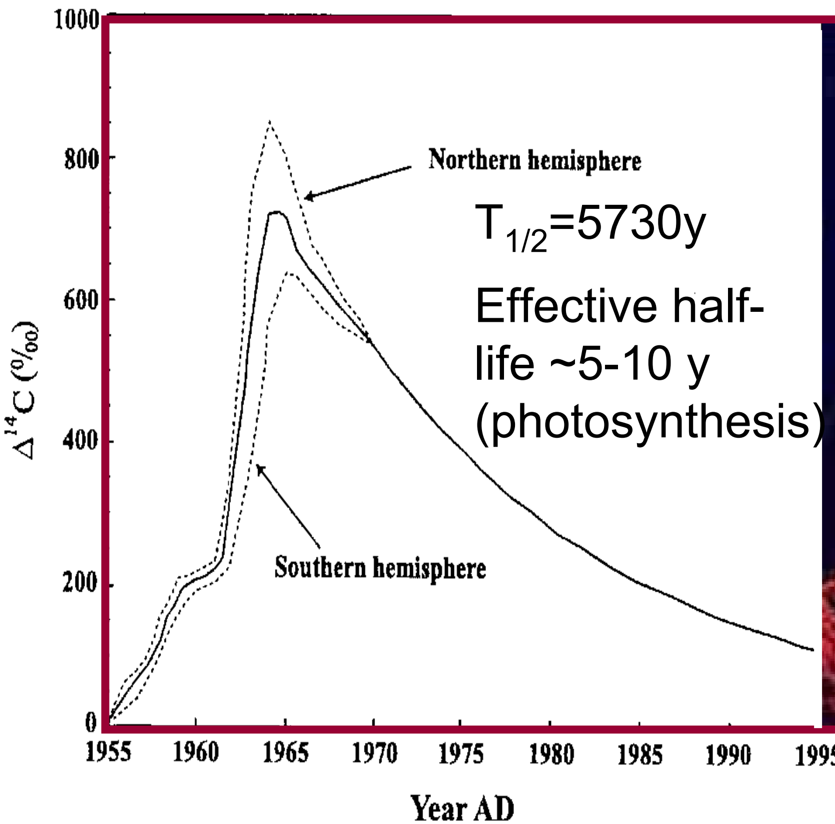
Rate of deaths due to the atomic bomb



(Oughterson AW and Warren S : Medical Effects of the atomic bomb in Japan. McGraw-Hill, New York, 1956 より改変)

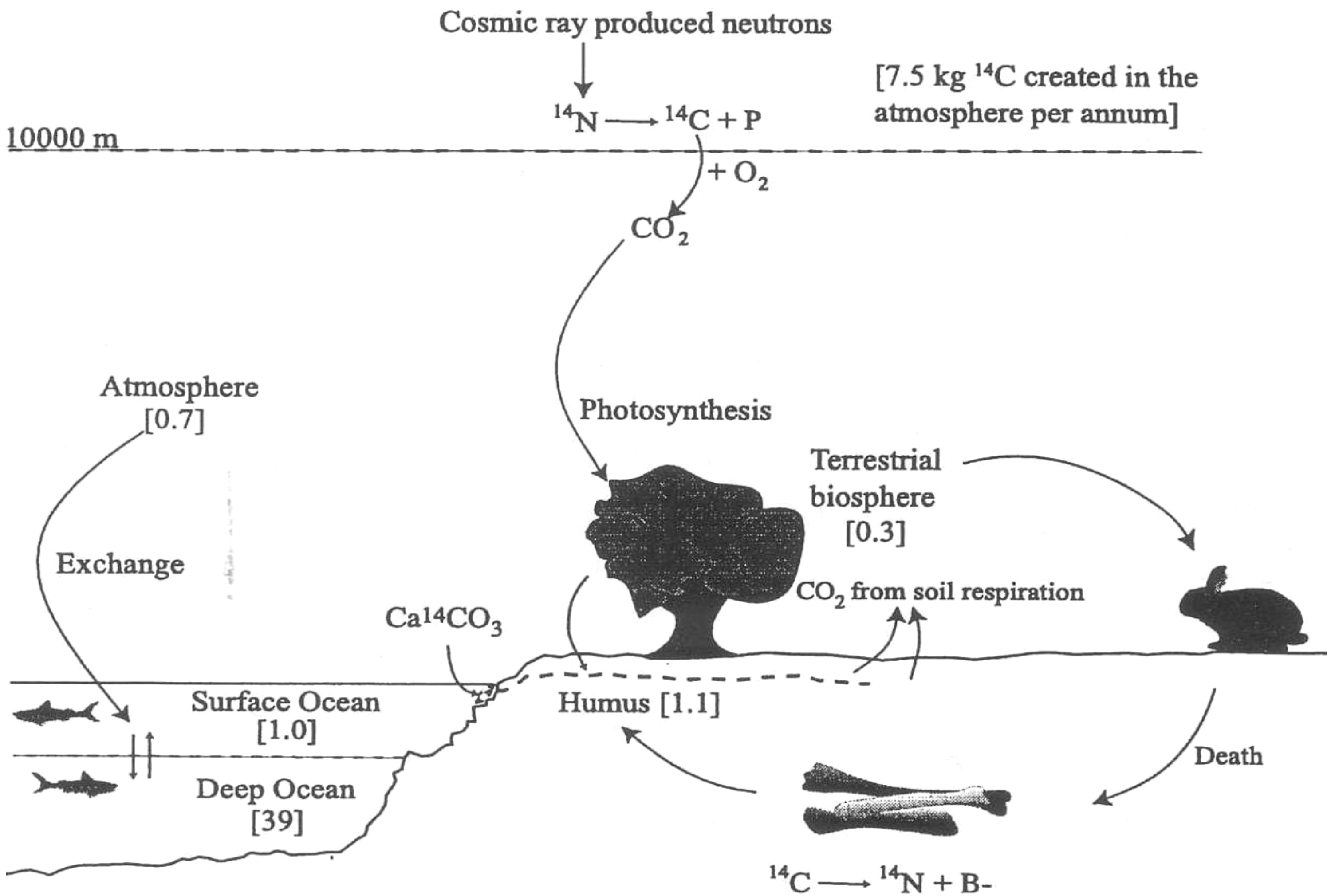
Radiation Effects of a Nuclear Bomb

Beside shock, blast, and heat a nuclear bomb generates high intensity flux of radiation in form of γ-rays, x-rays, and neutrons as well as large abundances of short and long-lived radioactive nuclei which contaminate the entire area of the explosion and is distributed by atmospheric winds worldwide.



^{14}C distribution

+ nuclear test related ^{14}C production



Nuclear Bomb related Radiation Production

RELATIONSHIP OF BLAST AND INITIAL RADIATION

— Air and Surface Bursts —

BLAST OVERPRESSURE (psi)	INITIAL NUCLEAR RADIATION (rad) 200 KT	500 KT	1 MT
1	Negligible	Negligible	Negligible
2	Negligible	Negligible	Negligible
5	Negligible (30)	Negligible (5)	Negligible (5)
10	10 (1,200)	Negligible (350)	Negligible (90)
12	25 (2,200)	1 (700)	Negligible (250)
15	80 (6,200)	10 (2,800)	2 (1,200)
20	2,600 (14,000)	650 (8,100)	250 (4,500)

Air bursts are at heights to maximize extent of 10 psi. Values in parentheses are for surface bursts.

Adapted from U.S. Department of Defense and Department of Energy, Effects of Nuclear Weapons, Revised Edition, 1977.

The units rad (rem) are a measure of radiation exposure!

Monitoring radiation intensity

Classical Unit: 1 Curie [Ci] $$1\left[Ci\right]=\frac{dN}{dt}=3.7\cdot 10^{10}\left[\frac{decays}{s}\right]$$

Modern Unit: 1 Becquerel [Bq] $$1\left[Bq\right]=\frac{dN}{dt}=1\left[\frac{decay}{s}\right]$$

The so-called dosimetry units (rad, rem) determine the amount of damage radioactive radiation can do to the human body. They depend on the kind and nature of the incident radiation

(X-rays, γ-rays, α-particles, β-particle, or neutrons).

It also depends on the energy loss of the particular radiation and the associated ionisation effects in the human body material.

Radiation Detection

Radiation Exposure & Dosimetry

Dose: $$D = \frac{E}{m}$$

Amount of energy *E* deposited by radiation into body part of mass *m*.

unit Rad or Gray

Equivalent Dose: $$H = Q \cdot D$$

Radiation independent dose
Q is normalization factor which accesses the individual body damage done by the particular kind of radiation

Unit Rem or Sievert

Photons:	Q=1
Neutrons: E<10keV	Q=5
Neutrons: E>10keV	Q=15
Protons:	Q=5
Alphas :	Q=20

UNITS OF RADIATION MEASUREMENT

Dosage units:

The Sievert (Gray) is a measure of biological effect.

1 Gray (Gy) = 1 Joule/kg (Energy/mass)

1 Sievert (Sv) = Gray x Q, where Q is a "quality factor" based on the type of particle.

Q for electrons, positrons, and x-rays = 1 Q = 3 to 10 for neutrons, protons dependent upon the energy transferred by these heavier particles.

Q = 20 for alpha particles and fission fragments.

Converting older units:

1 rad = 1 centigray = 10 milligrays (1 rad = 1cGy = 10 mGy)

1 rem = 1 centisievert = 10 millisieverts (1 rem = 1cSv = 10 mSv)

Nominal background radiation absorbed dose of 100 mrad/year = 1 mGy/yr.

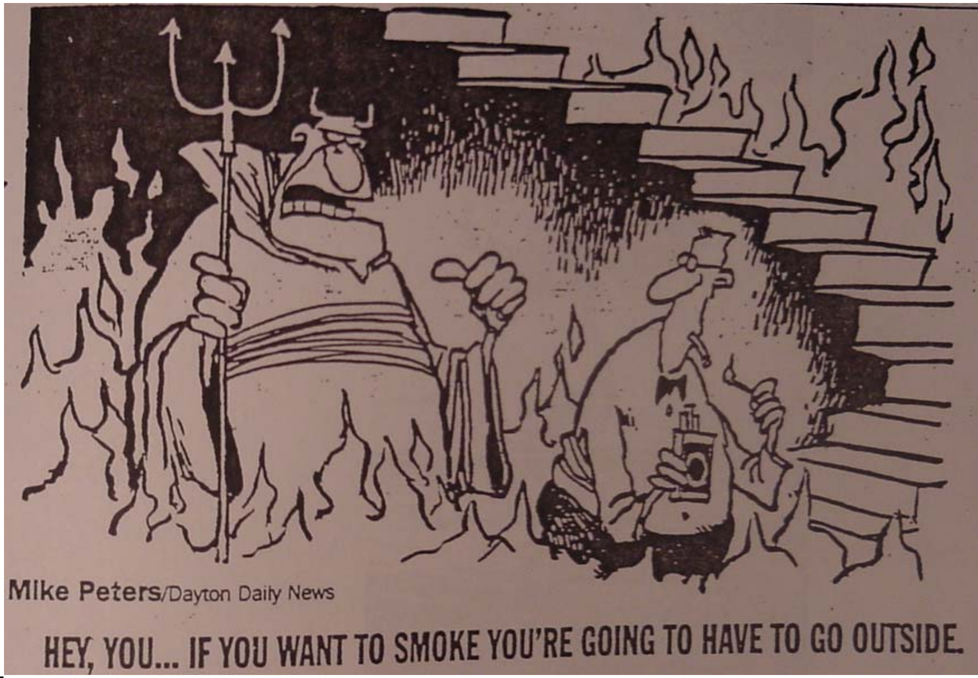
Nominal background radiation dose biological equivalent of 100 mrem/year = 1mSv/yr.

Occupational whole body limit is 5 rem/yr = 50 mSv/yr.

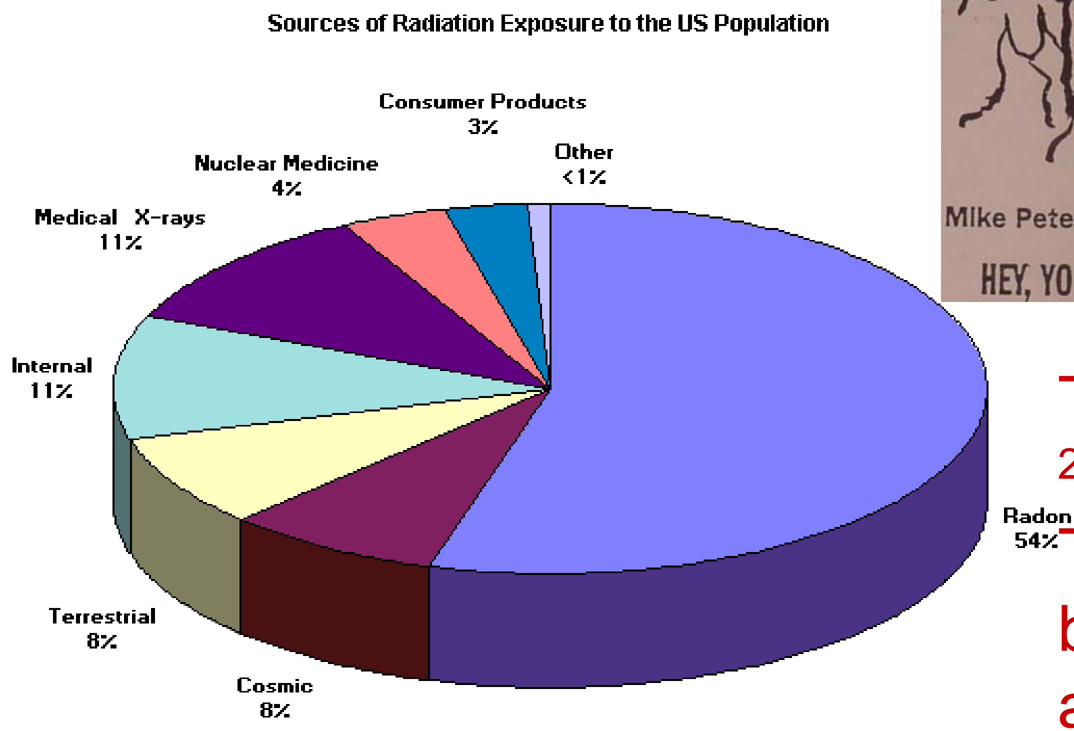
2.5 mrem/hr or 25 uSv/hr is maximum average working level in industry.

Exposure rate from Naturally Occurring Radioactive Material; an empirically derived conversion factor for Ra-226 decay series: 1.82 microR/ hour = 1 picoCurie/gram.

Exposure to Natural and Man-made Radioactivity



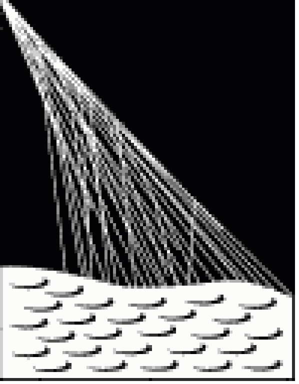
Total average annual dose:
H ≈ 250-300 mrem



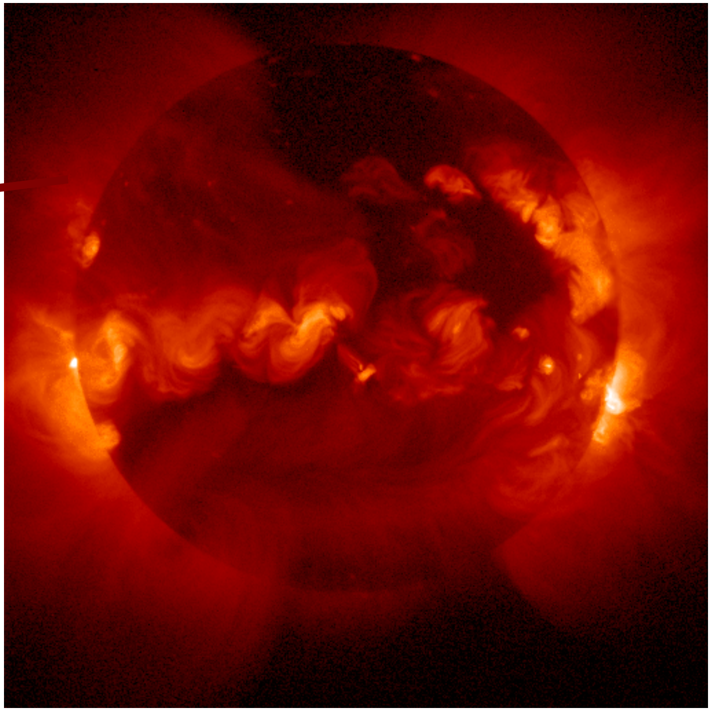
Tobacco contains α-emitter ^{210}Po with $T_{1/2}$=138.4 days. Through absorption in the bronchial system smoking adds 280 mrem/year to the annual dose of US population

Average annual dose from nuclear bomb test fallout $H_{fo} \approx 0.06$ mrem.

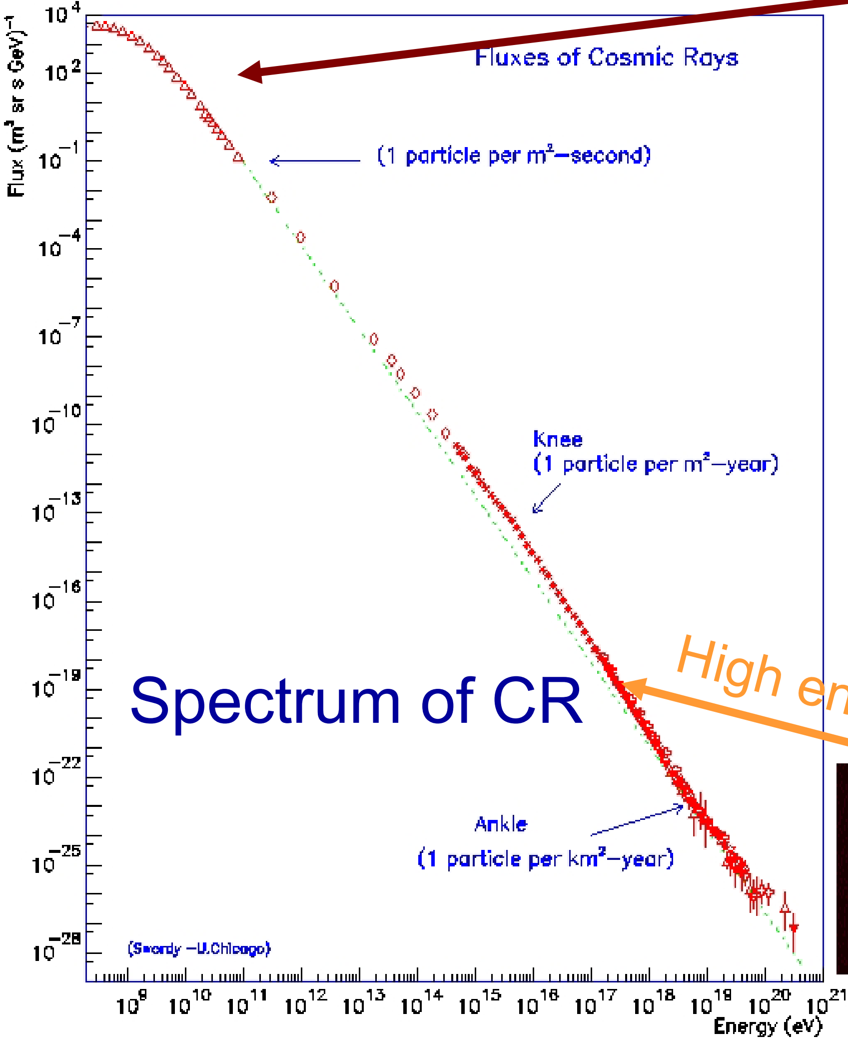
Sources of Natural and Radioactivity



Cosmic Ray Bombardment



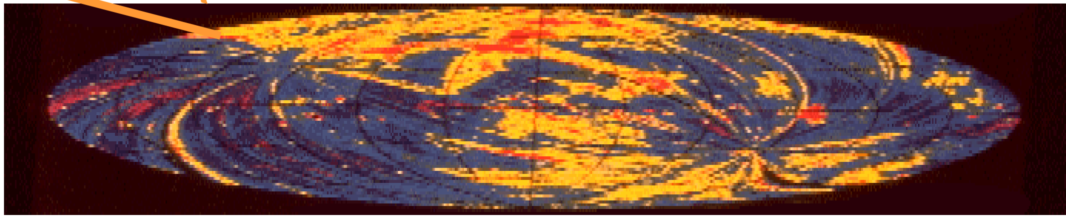
Low energy CR



High energy CR

Cosmic Rays origin from:

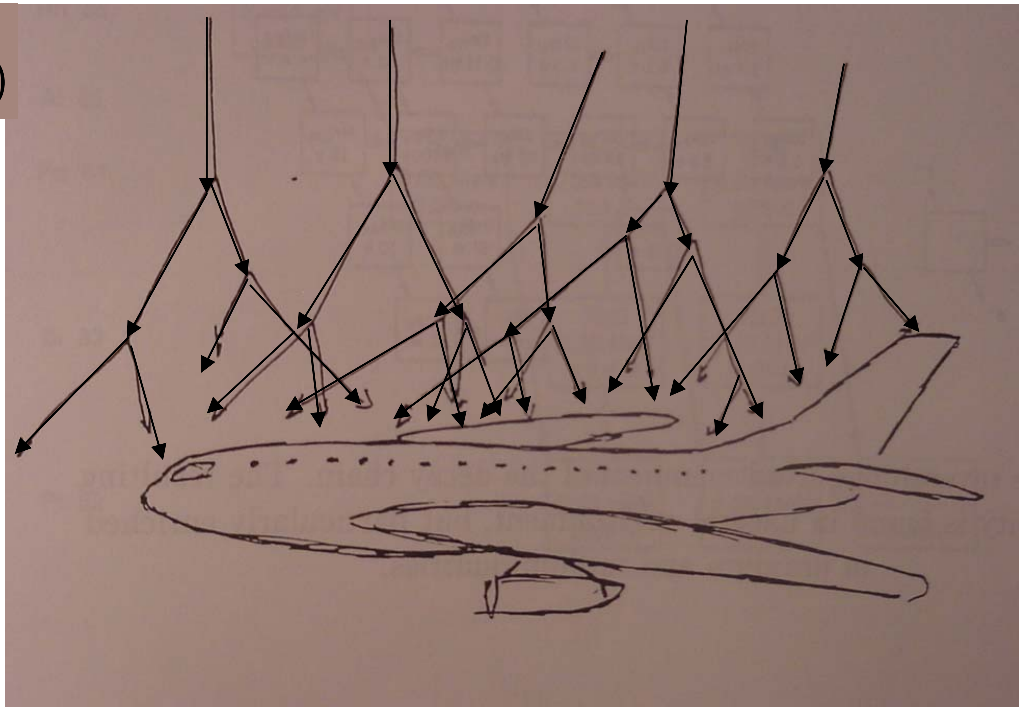
- solar flares;
- distant supernovae;



Cosmic Rays in High Altitude

Earth is relatively protected from cosmic rays through atmosphere shield; typical exposure is H=3.2 mrem/h. Mountain climbers and airline crews and passengers are exposed to higher doses of radiation. Dose doubles every 1500 m in height. At 10 km height dose is about 100 times sea-level dose H=0.32mrem/h.

$$D_{(h_n = n \cdot 1500m)} = 2^n \cdot D_{(h_0 = 1500m)}$$



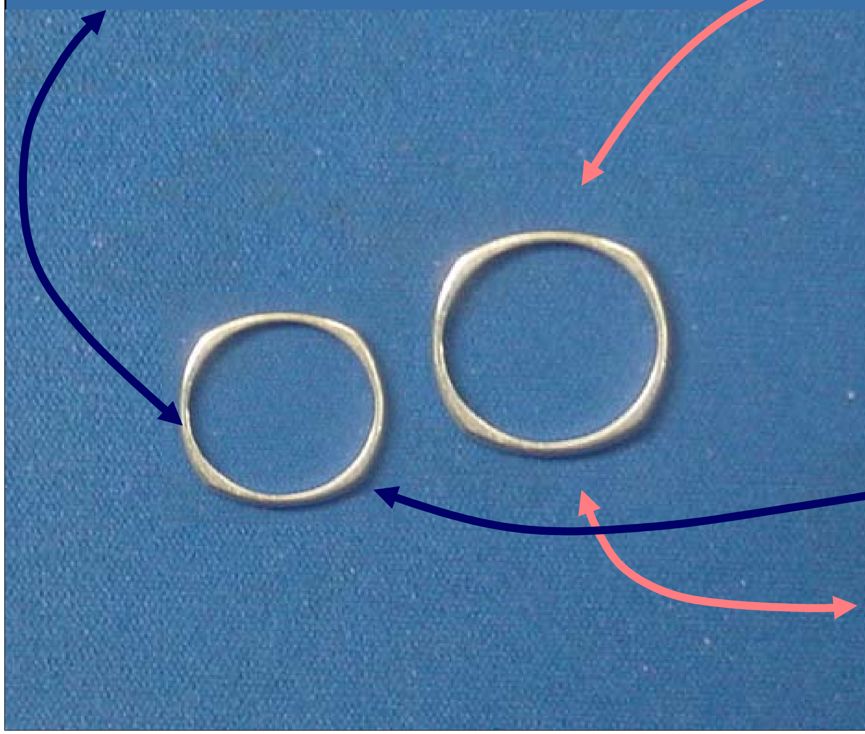
Example: Total dose H:

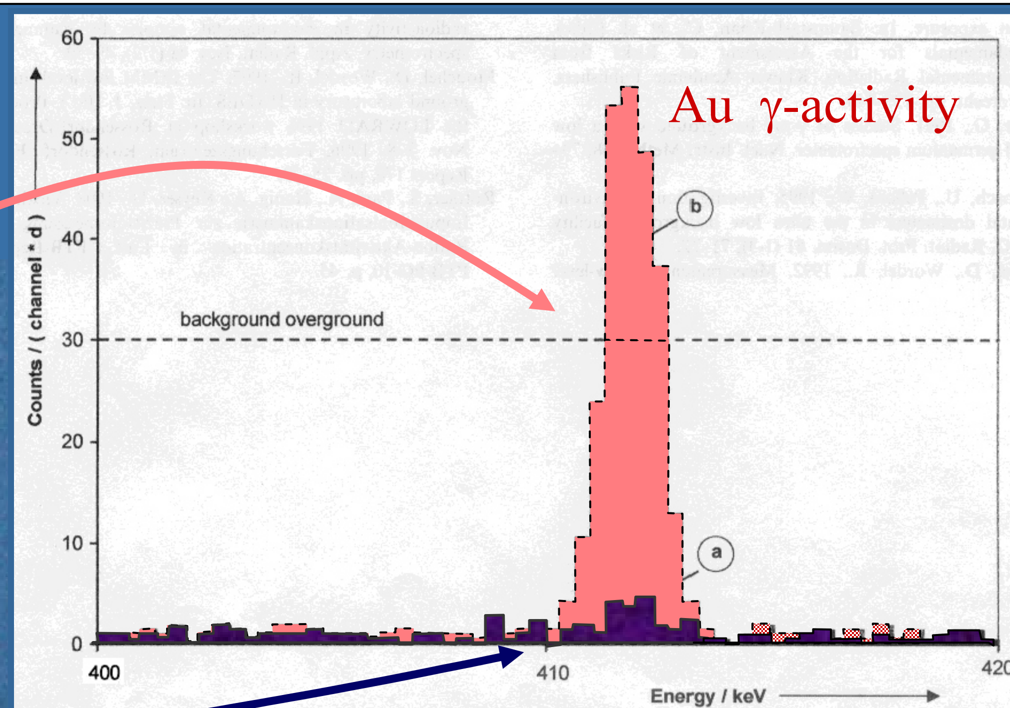
- after 10h of flight: H=3.2 mrem,
- for round trip: H=6.4 mrem
- Frequent flyer with about 10 transatlantic flights/year H=64 mrem/year.

Compare to natural dose (~200 mrem/y) !

Observable Effects!

Wife's ring
with ground
level dose!

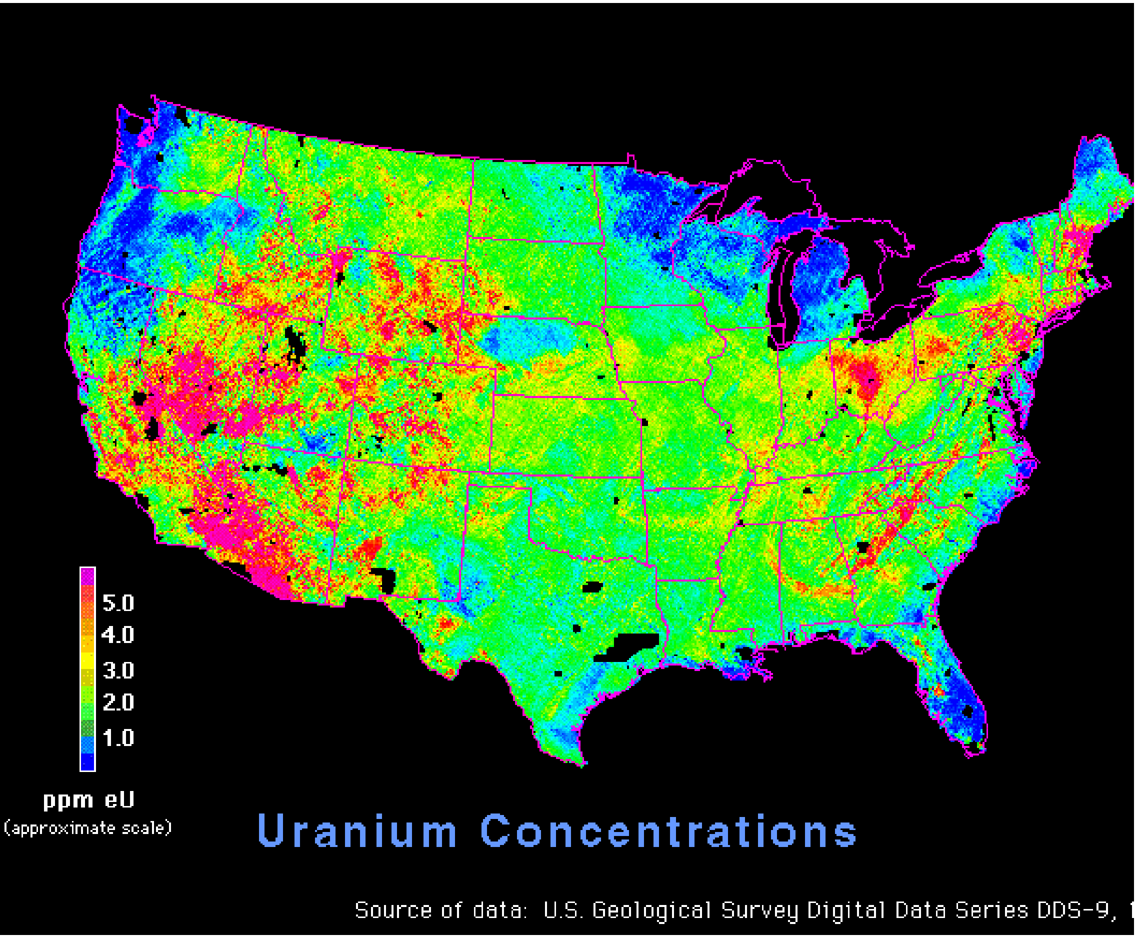


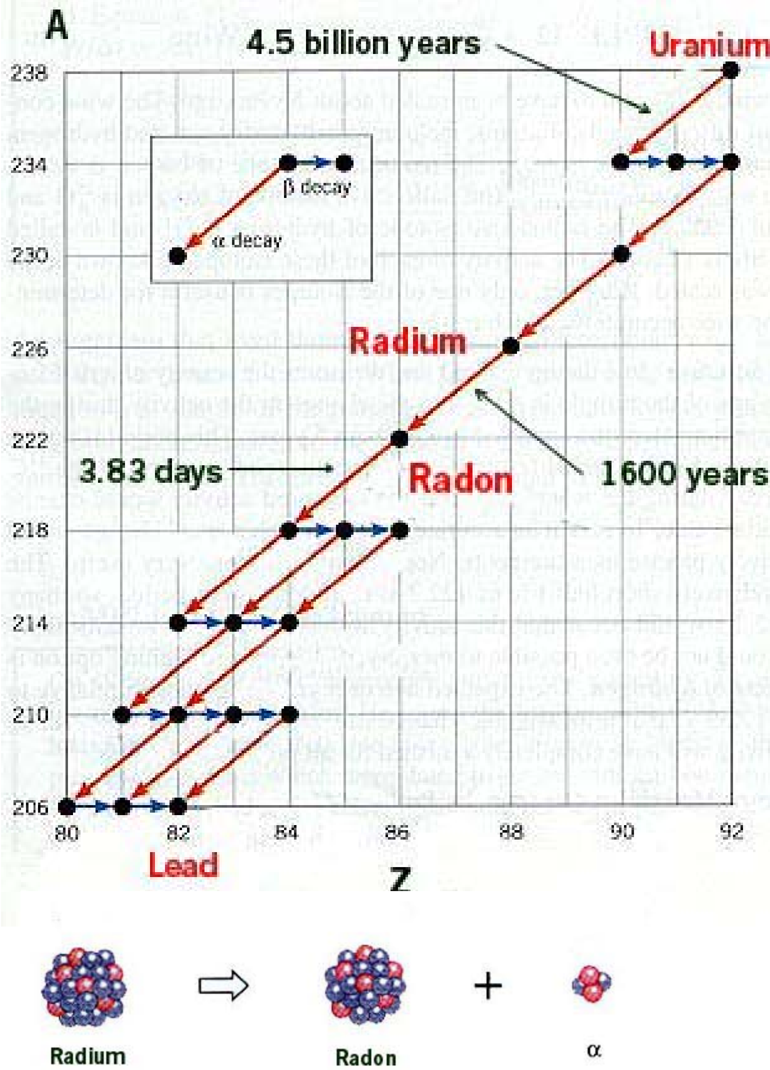


Husband's ring
with transatlantic
high altitude dose

⇨ 8 times
more dose

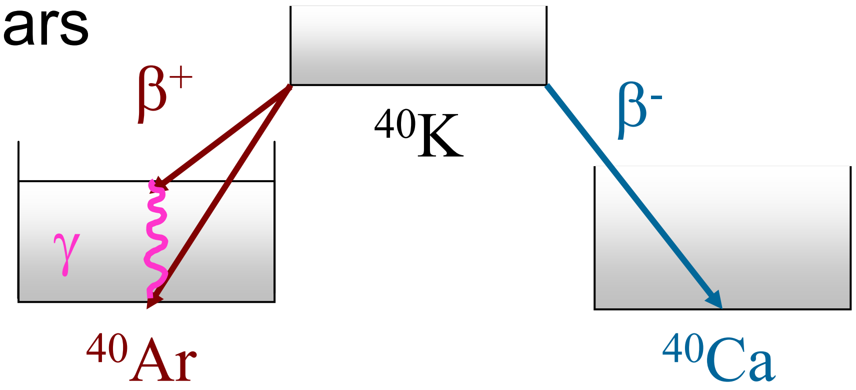
Natural Radioactivity in the US

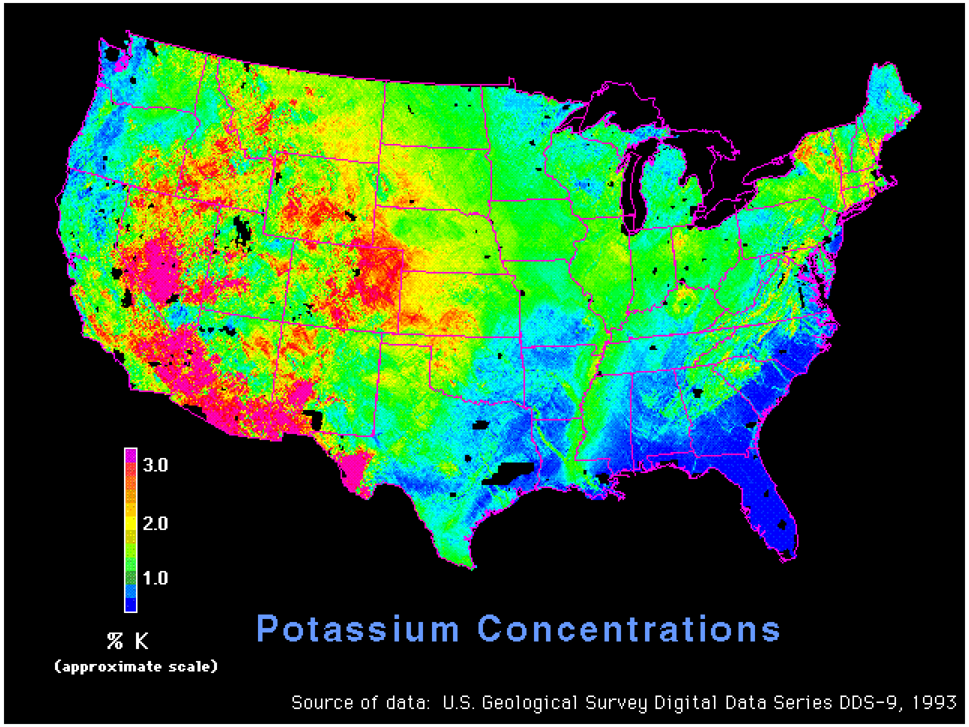




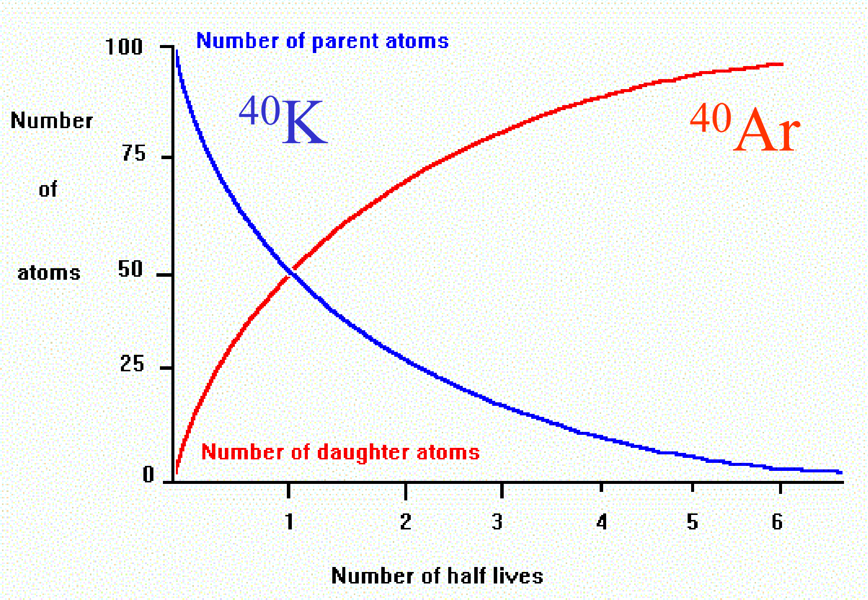
Long lived ^{40}K Radioactivity

^{40}K has a half-life of $T_{1/2}=1.28 \cdot 10^9$ years
its natural abundance is 0.021 %





Potassium decay to Argon



Internal γ Glowing

On average, 0.27% of the mass of the human body is potassium K of which 0.021% is radioactive ^{40}K with a half-life of $T_{1/2}$=1.25·10^{9} [y]. Each decay releases an average of E_{avg}= 0.5 MeV β- and γ-radiation, which is mostly absorbed by the body but a small fraction escapes the body.

Calculate, how many radioactive ^{40}K atoms are in your body system!

Some Mass and Number Considerations

* mass of the body: m_{body}
* mass of potassium K in the body: $m_K = 0.0027 \cdot m_{body}$
* mass of radioactive ^{40}K in the body: $m_{^{40}K} = 0.00021 \cdot m_K = 5.67 \cdot 10^{-7} \cdot m_{body}$

$$40\,g \text{ of } {}^{40}K \equiv 6.023 \cdot 10^{23} \text{ atoms}$$

$$m_{^{40}K} = 5.67 \cdot 10^{-7} \cdot m_{body}[g] \equiv \frac{6.023 \cdot 10^{23} \cdot 5.67 \cdot 10^{-7} \cdot m_{body}}{40}[particles] = N_{^{40}K}$$

$$\frac{N_{^{40}K}}{m_{body}} = 8.54 \cdot 10^{15}\,[particles/g]$$

to calculate $N_{^{40}K}$, you need the body mass m_{body} in gramm.

for 80 kg body: $N_{^{40}K} = 6.83 \cdot 10^{20}\,[particles]$

Example: ^{40}K

Calculate the absorbed body dose over an average human lifetime of t = 70 y for this source of internal exposure.

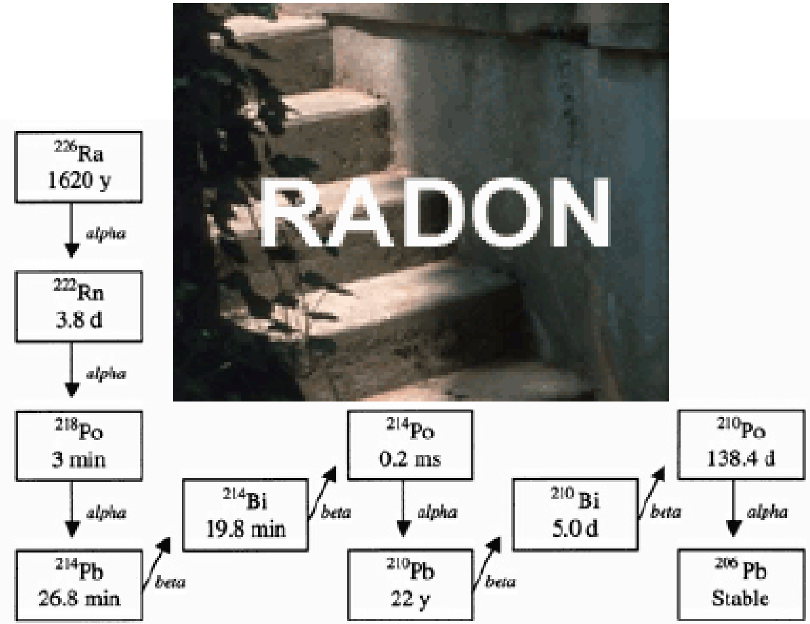
* $Dose$: $$D = \frac{E_{absorbed}}{m_{body}} = t \cdot A(^{40}K) \cdot \frac{E_{avg}}{m_{body}}$$

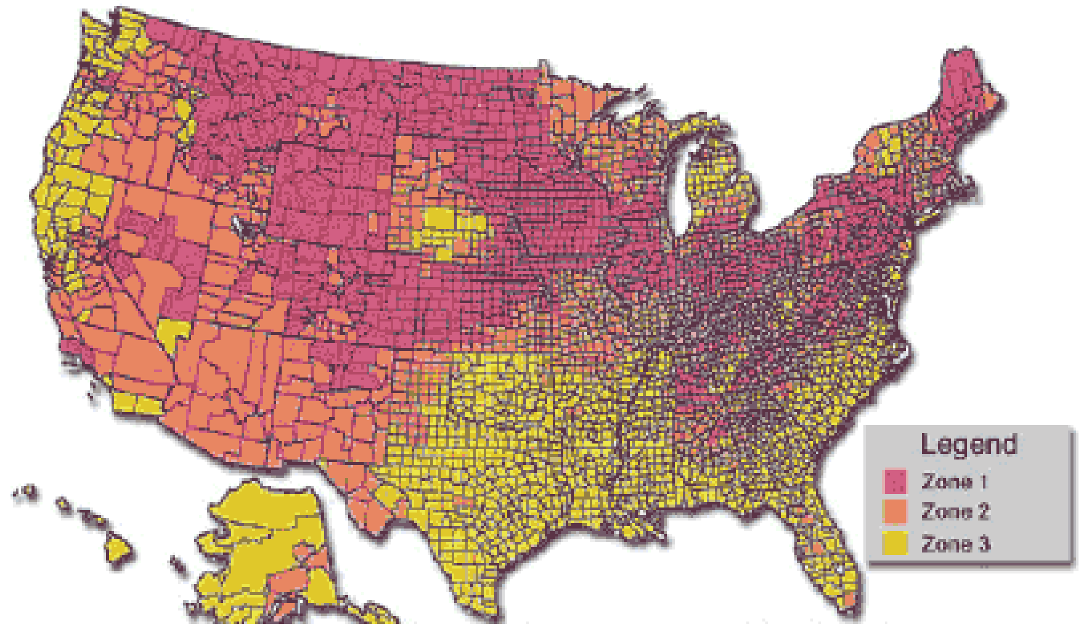
* $Activity$: $$A(^{40}K) = \lambda \cdot N_{^{40}K} = \ln 2 / T_{1/2} \cdot N_{^{40}K}$$

$$D = 70\,[y] \cdot \frac{\ln 2}{1.25 \cdot 10^{9}\ [\mathrm{y}]} \cdot (8.54\ 10^{15}\ [g^{-1}] \cdot m_{body}) \cdot \frac{0.5\ [MeV]}{m_{body}}$$

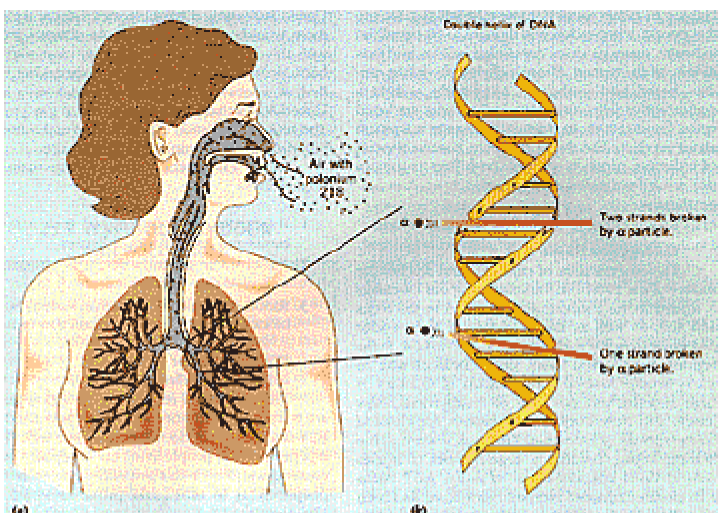
$$D = 1.66 \cdot 10^{11} \left[MeV / kg\right] = 2.63 \cdot 10^{-2} \left[J / kg\right] = 2.63 \cdot 10^{-2} \left[Gy\right] = 2.63 [rad]$$

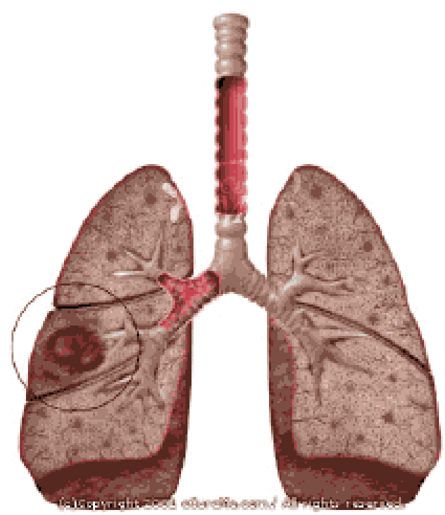
$$with: \quad 1\left[eV\right] = 1.602 \cdot 10^{-19} \left[J\right]$$

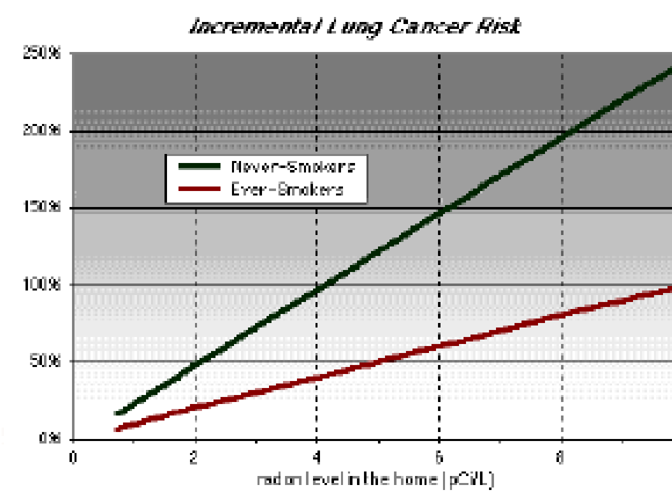




- Radon is a radioactive inert gas.
- Radon progenies build up in confined space – are breathed in, stick to surface of airways and emit α-particles.
- Basal cells in bronchial epithelium are believed to be target cells for cancer.







Annual Average Total Effective Dose Equivalent to the U.S. Population

Natural Background, Radon	200 mrems
Cosmic and Terrestrial source	56
Medical and Dental X-Rays	54
Internal Source, ^{40}K	40
Tobacco Smoking	280
Other Consumer Products	10
Total, All Population	640
Total, Non-Smokers	360

Comparing the Risks: Radiation, Smoking, and Driving

Procedure	Dose	Chance of Death	Equivalent to: Number of Cigarettes Smoked	Equivalent to: Number of Highway Miles Driven
	Bone Marrow	*From Leukemia*		
^{131}I treatments for thyrotoxicosis	15 rems	3×10^{-4}	2200	5357
Chest radiograph	10 mrems	2×10^{-7}	1.5	3.6
Skull examination	78 mrems	1.6×10^{-6}	11.4	28
Barium enema	875 mrems	17.5×10^{-6}	128	313

A full set of dental X-rays using a high energy X-ray machine and E-speed film has a relative cancer risk equivalent to that of smoking ~2-3 cigarettes.

Release of Radiation by Nuclear Bomb

Nuclear bomb causes sudden release of a high flux on:

❑ γ-rays	$E=h\nu \approx 1\text{-}10$ MeV electromagnetic waves
❑ x-rays	$E=h\nu \approx 1\text{-}100$ keV electromagnetic waves
❑ α-radiation	^4He nuclei
❑ β-radiation	electrons and positrons
❑ neutrons	neutrons

❑ heavy radioactive species (cause for delayed radiation)

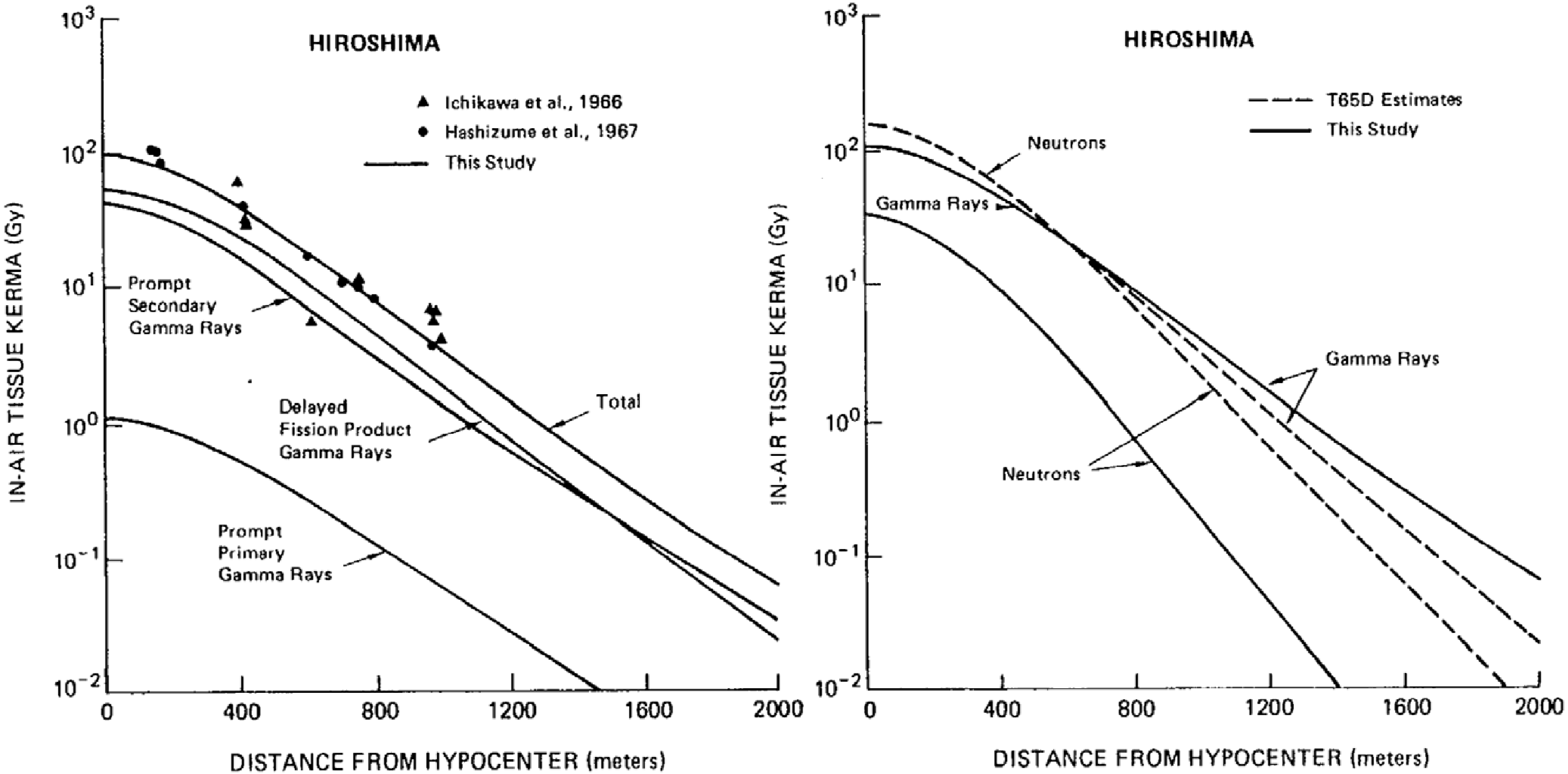
The prompt radiation is absorbed in the surrounding atmosphere according to exponential absorption law

$$I(d) = I_0 \cdot e^{-\mu \cdot d}$$

I_0 is the initial intensity and μ is the attenuation coefficient determined by the interaction probability of radiation with molecules and atoms in air.

Hiroshima radiation spread data

Primary γ ray originated low dose of <100 rad near the hypocenter, secondary γ-ray originated dose of >100 rad within 1500 m radius



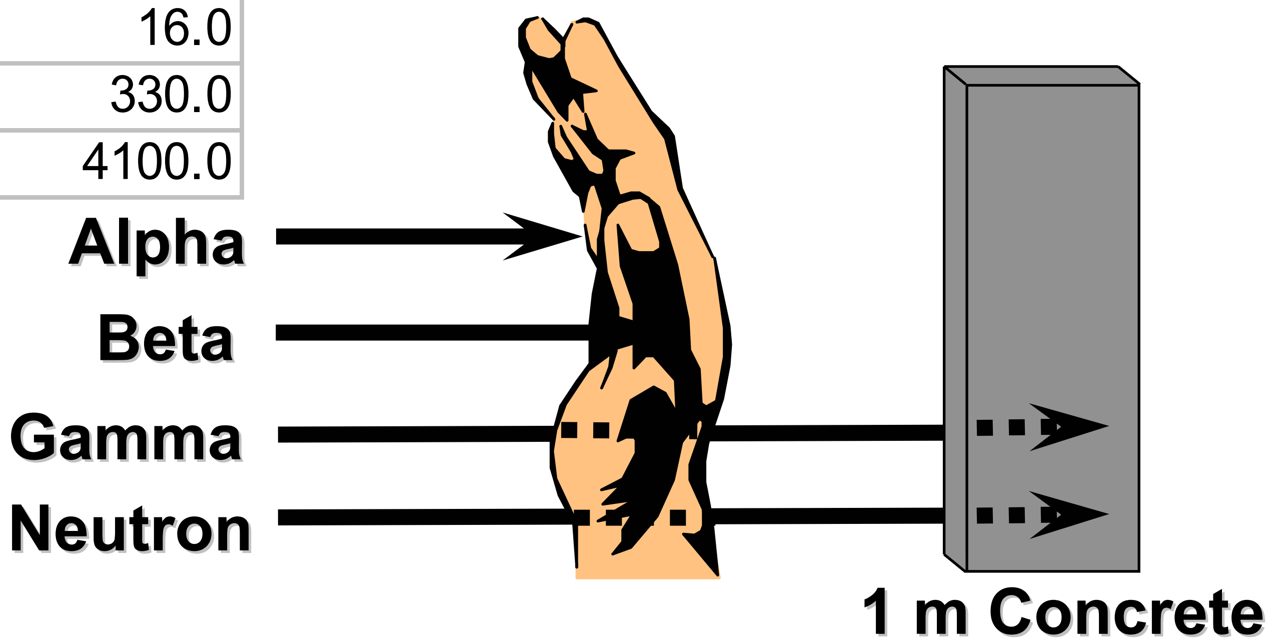
Kerma versus distance for the various components of the radiation in Hiroshima (data from Kerr et al.[10]). doses are in grays (1 Gy = 100 rad).

Absorption probability

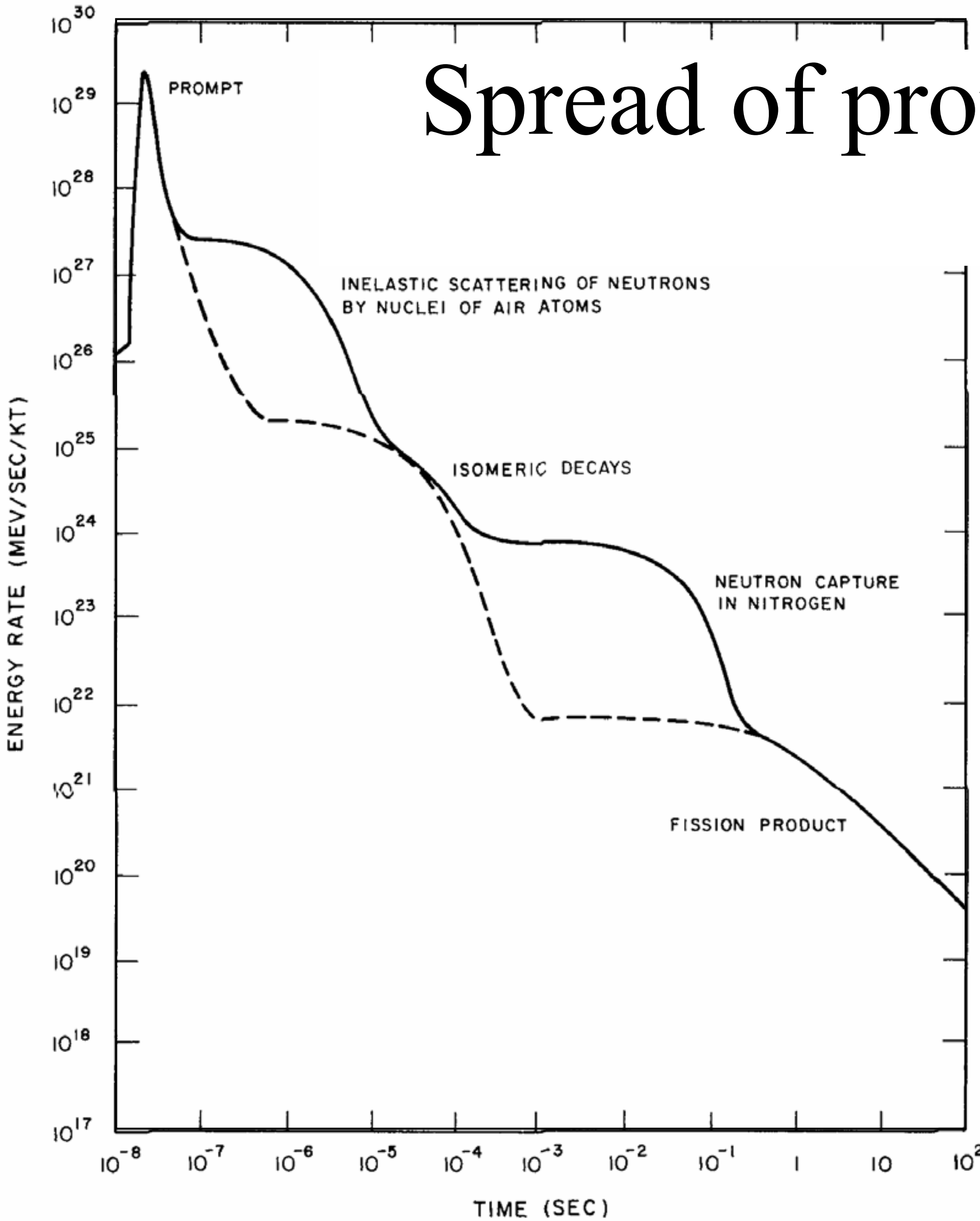
Attenuation coefficient μ depends on energy and nature of particle, medium and interaction probability. High Coulomb scattering probability for charged particles, causes high absorption probability, results in short range!

Energy	Range(α)	Range(β)
keV	cm	cm
10	0.01	0.2
100	0.10	16.0
1000	0.50	330.0
10000	10.50	4100.0

Main component gammas & neutrons



Spread of prompt & secondary γ-radiation

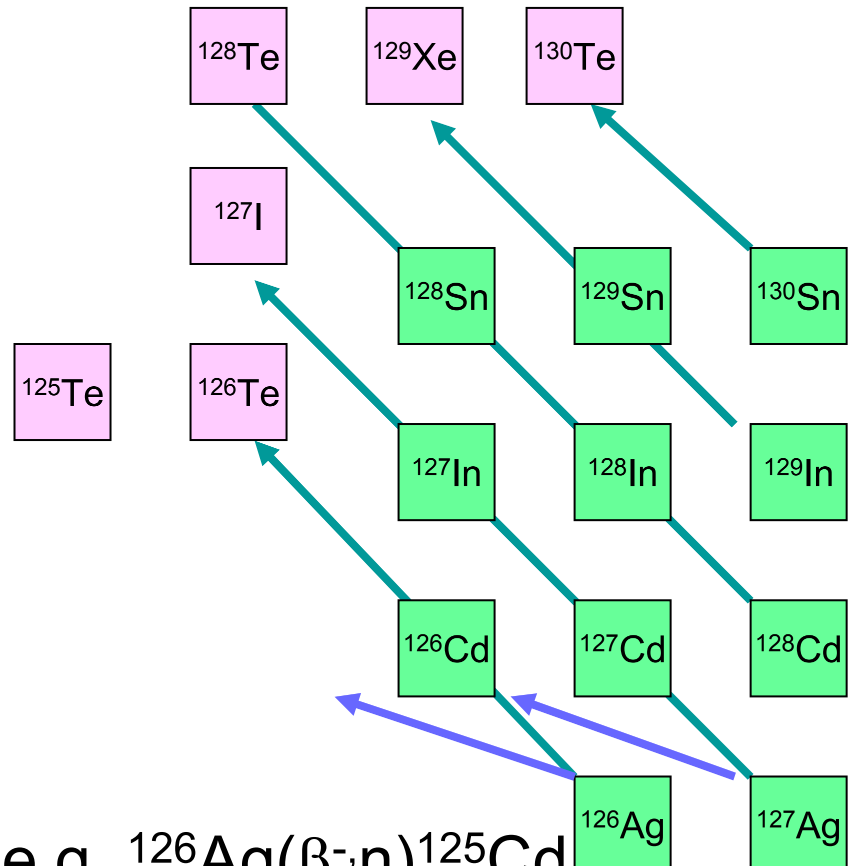


Calculated time dependence of the gamma-ray energy output per kiloton energy yield from a hypothetical nuclear explosion. The dashed line refers to an explosion at very high altitude.

Neutrons originated secondary γ radiation by inelastic neutron scattering as well as by neutron capture on nitrogen isotopes in the surrounding air. Secondary γ-production enhances radiation flux and radiation extension.

Fission products

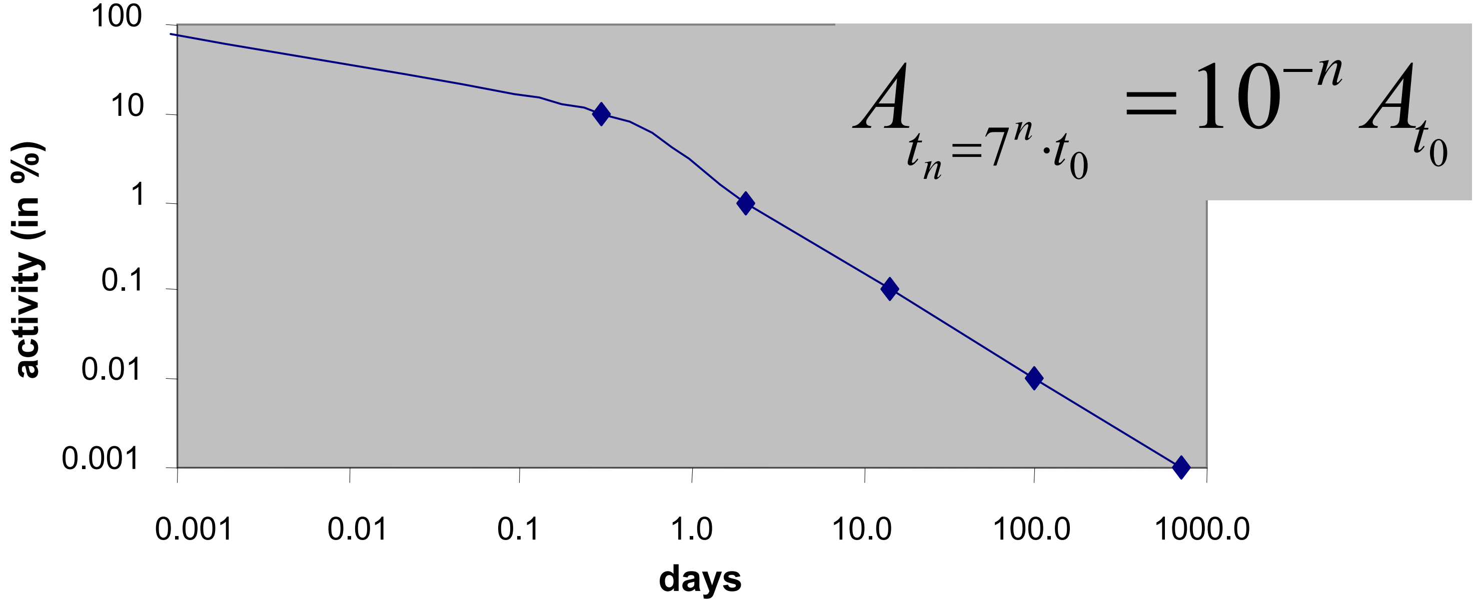
Production of neutron-rich radioactive isotopes in the mass 80-130 range which decay by β^- decay or by β-delayed neutron emission
Back to stable isotopes.
Decay time scale depends
On the associated half-lives which determine the flux and time scale for delayed radiation exposure.



e.g. $^{126}Ag(\beta^-,n)^{125}Cd$
vs $^{126}Ag(\beta^-)^{126}Cd$

Decline by the "rule of seven"

This rule states that for every seven-fold increase in time following a fission detonation (starting at or after 1 hour), the radiation intensity decreases by a factor of 10. Thus after 7 hours, the residual fission radioactivity declines 90%, to one-tenth its level of 1 hour. After 7·7 hours (49 hours, approx. 2 days), the level drops again by 90%. After 7·2 days (2 weeks) it drops a further 90%; and so on for 14 weeks.



The rule is accurate to 25% for the first two weeks, and is accurate to a factor of two for the first six months. After 6 months, the rate of decline becomes much more rapid.

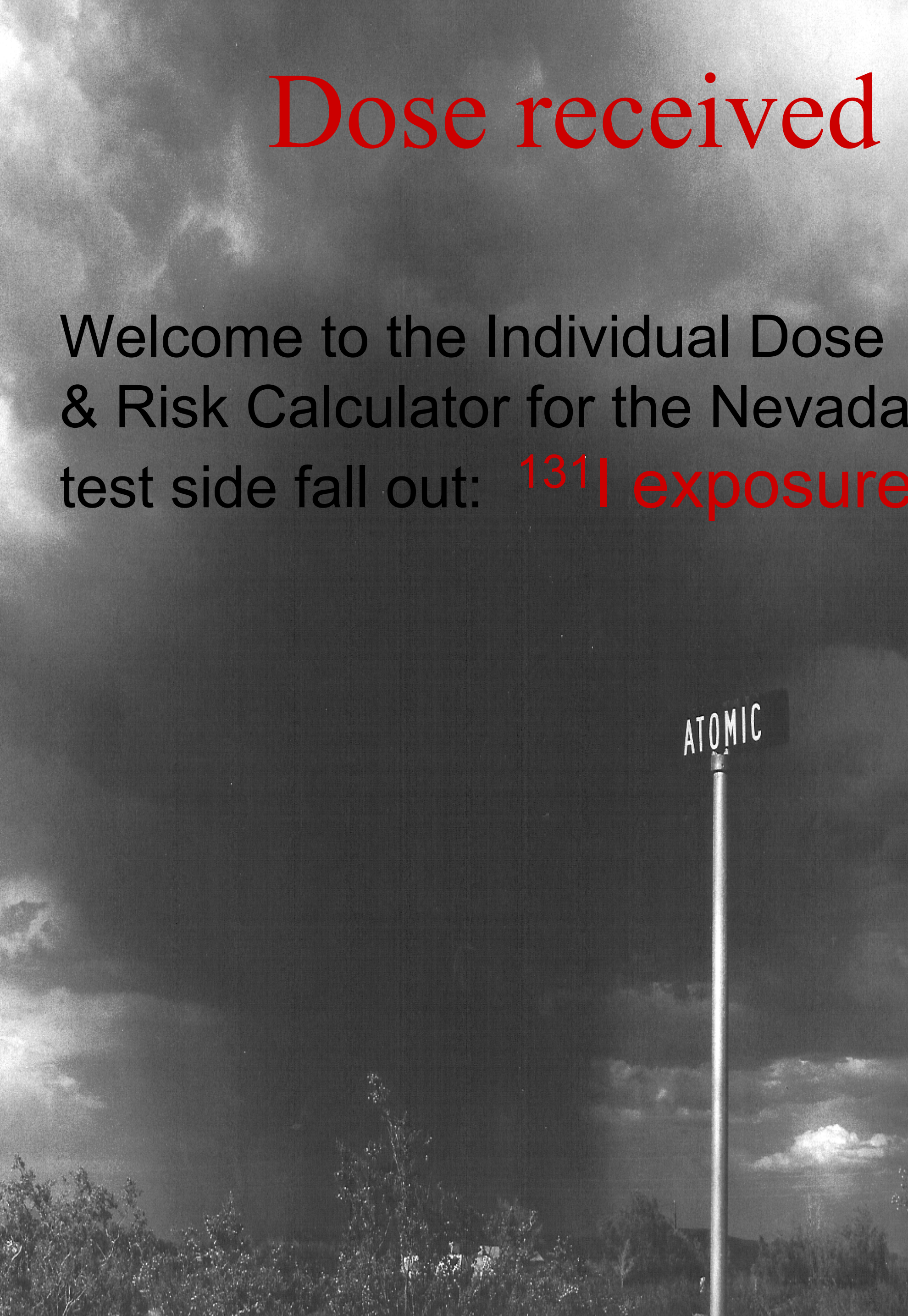
Table. Summary of average thyroid and red bone marrow doses (milliGray [mGy]) from NTS and global fallout received as a result of exposure to the most important radionuclides. The values are for adults at the time of the tests, unless otherwise specified. Blank spaces reflect negligible values of dose.

		NTS Fallout			Global Fallout		
Radionuclide	Half-life[a]	External Dose[b] (mGy)	Thyroid Internal Dose (mGy)	Red Bone Marrow Internal Dose (mGy)	External Dose[b] (mGy)	Thyroid Internal Dose (mGy)	Red Bone Marrow Internal Dose (mGy)
Tritium	12.3 y					0.07	0.07
Carbon-14	5730 y					0.1	0.1
Manganese-54	313 d				0.04		
Strontium-89	52 d		0.001	0.03			
Strontium-90	28.5 y			0.02		0.0009 [0.002][c]	0.2 [0.5][c]
Zirconium/Niobium-95	64 d	0.08			0.2		
Zirconium/Niobium-97	17 h	0.02					
Ruthenium-103	39 d	0.03			0.02		
Ruthenium-106	368 d		0.001	0.002	0.04		
Antimony-125	2.7 y				0.03		
Iodine-131	8 d	0.02	5 [30][c]	0.001		0.4 [2][c]	0.00009 [0.0002][c]
Tellurium/Iodine-132	3.3 d	0.1	0.06	0.001			
Iodine-133	0.9 d	0.02	0.04				
Cesium-136	13 d		0.002	0.002			
Cesium-137	30 y	0.01	0.009	0.009	0.3	0.1	0.1
Barium/Lanthanum-140	13 d	0.2		0.006	0.05		
Cerium-144	284 d				0.02		
Neptunium-239	2.4 d	0.02					
Rounded totals:							
- Adults		0.5	5	0.1	0.7	0.7	0.6
- Child born 1 January 1951			[30][c]			[2][c]	[0.9][c]

[a] y=years; d=days; h=hours.
[b] The external dose is equal for all organs of the body.
[c] Values in brackets are for a child born 1 January 1951

Dose received from bomb tests

Welcome to the Individual Dose & Risk Calculator for the Nevada test side fall out: ^{131}I exposure

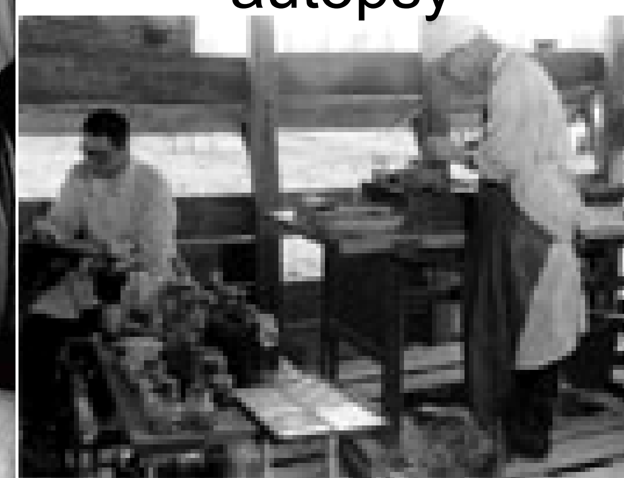


http://ntsi131.nci.nih.gov/

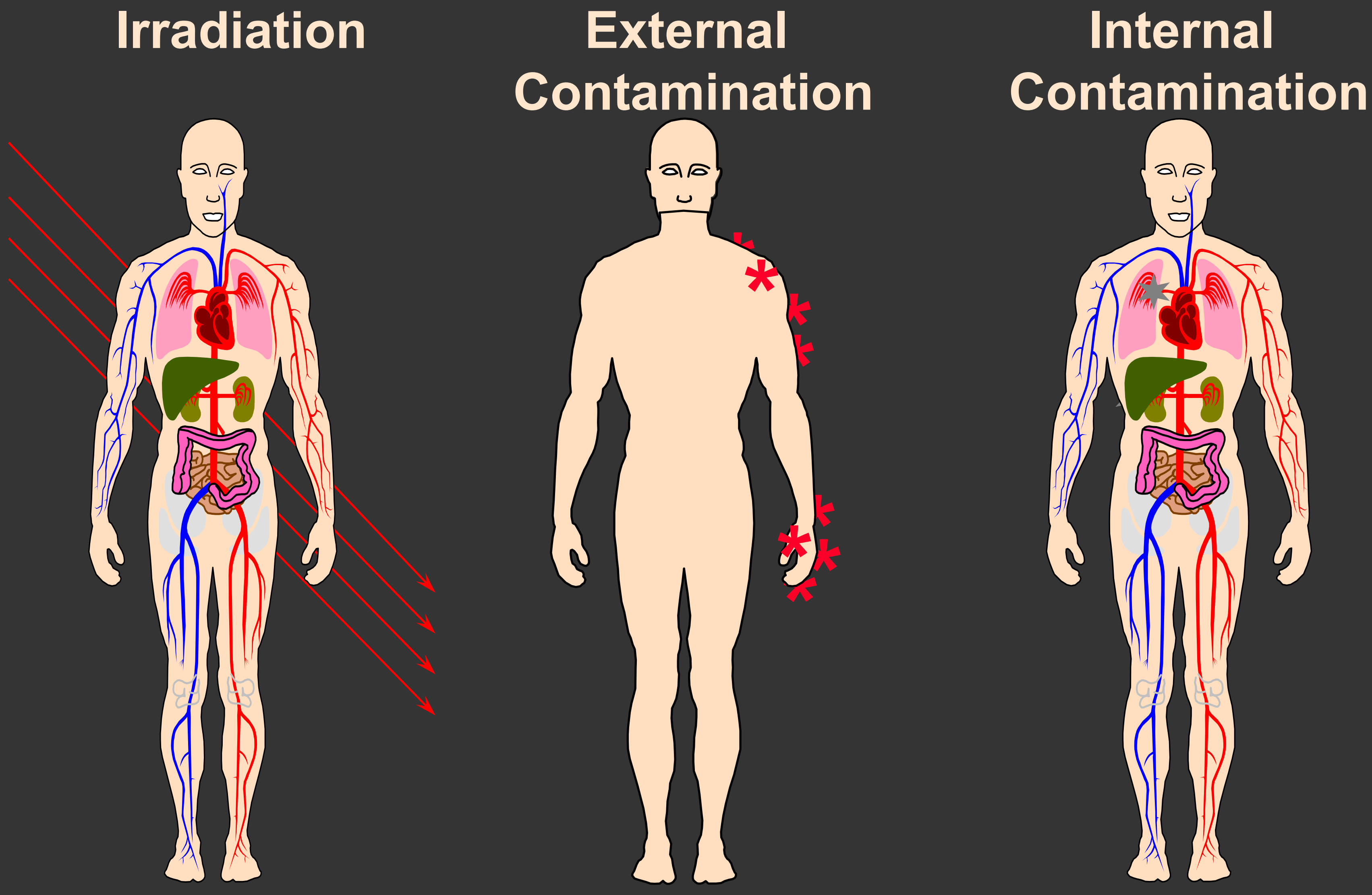
Studies of impact of ionizing radiation on the human body - Hiroshima -

US-Japanese teams medical tests, autopsies, human organ analysis, on-site radioactivity measurements …

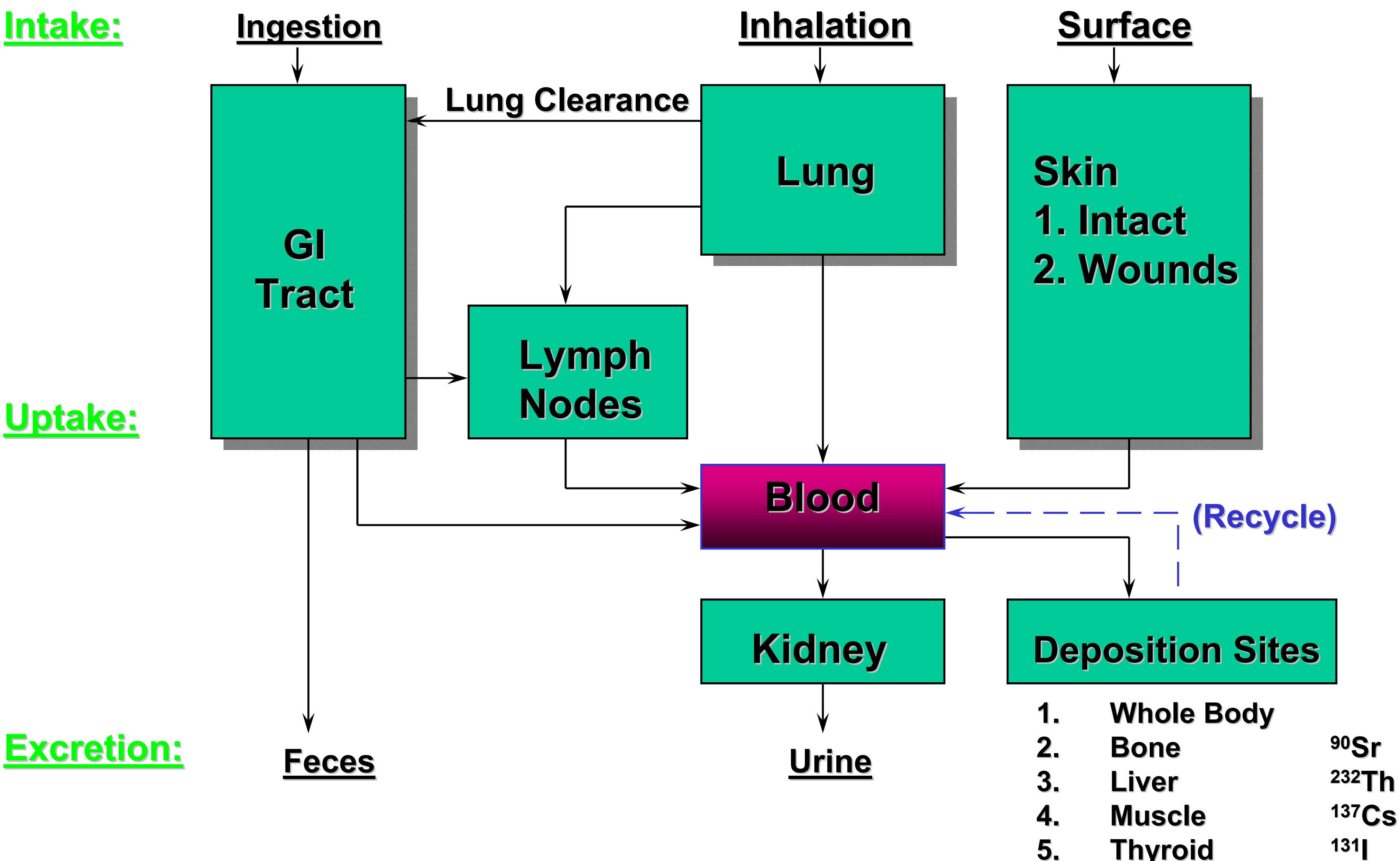
autopsy



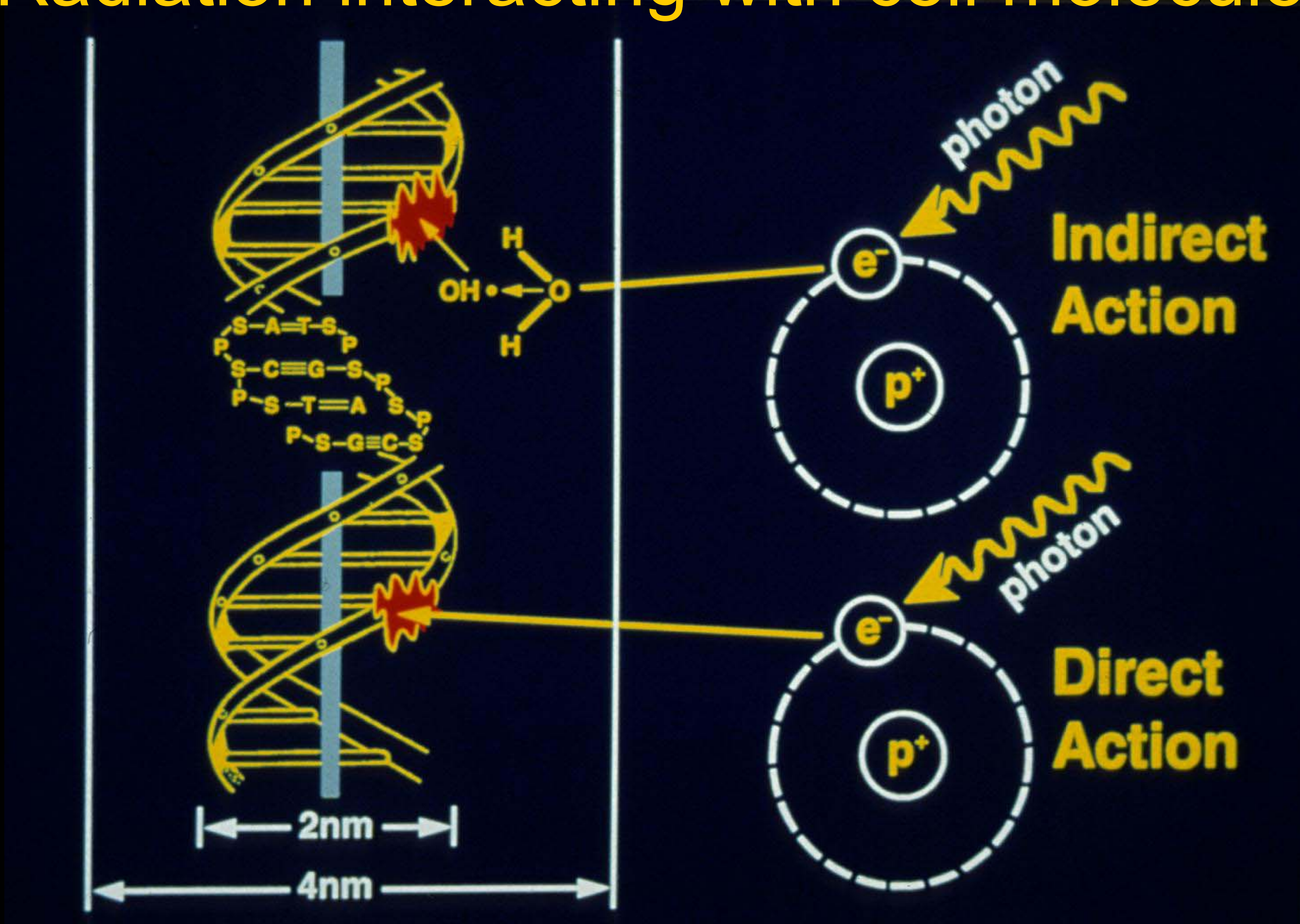
Radiation Exposure Types



Schematic Model of Radionuclide Uptake



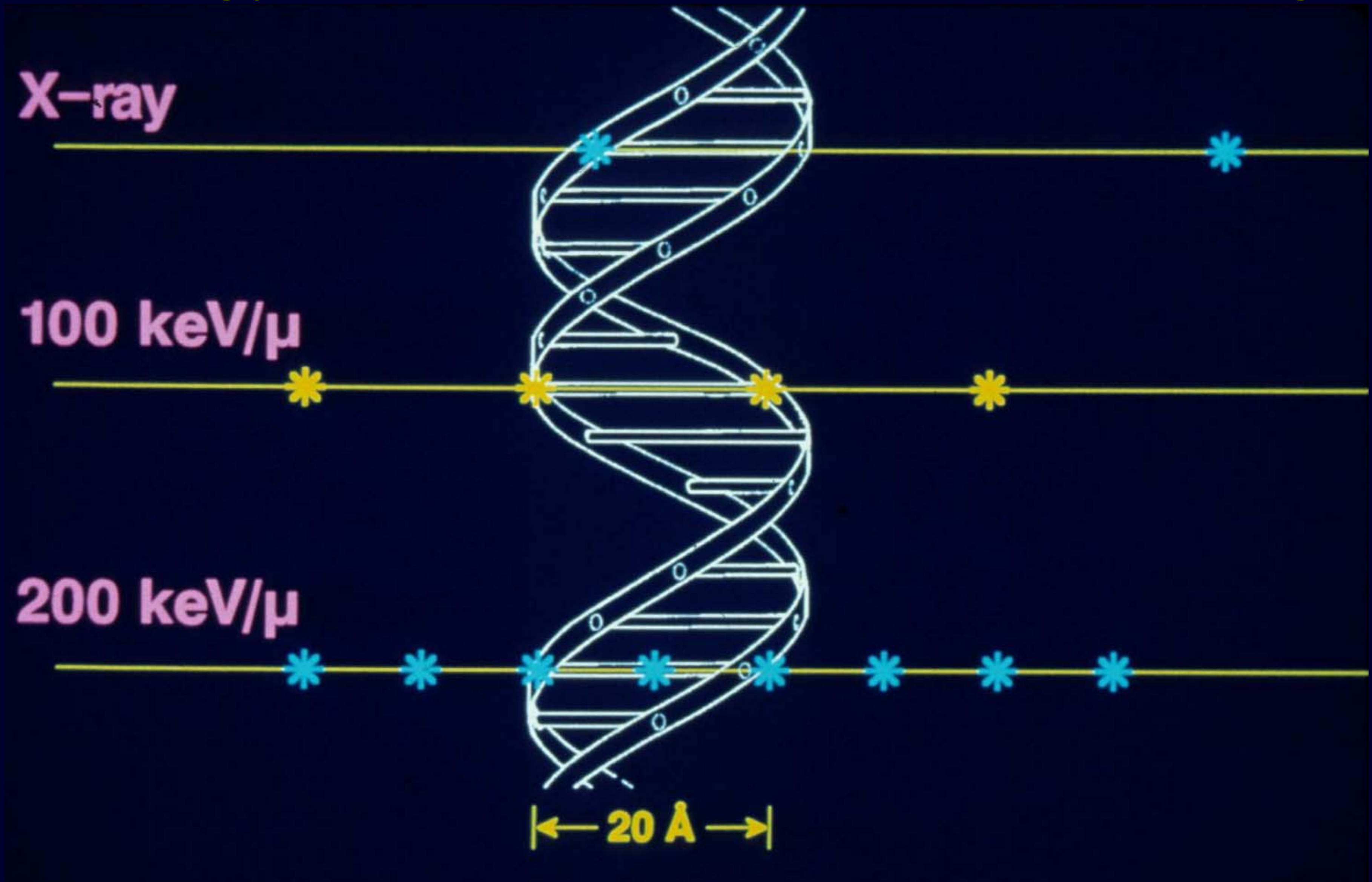
Radiation interacting with cell molecules



Sequence of Events in Indirect Action

$T_{1/2}$ in sec	Incident X-ray photons
	↓
10^{-15}	Fast electrons
	↓
10^{-5}	Ion radicals
	↓
10^{-5}	Free radicals
	↓
	Macromolecular changes from breakage of chemical bonds
	↓
	Biological effects
days	- cell killing
generation	- mutation
years	- carcinogenesis

Energy dependence of radiation damage



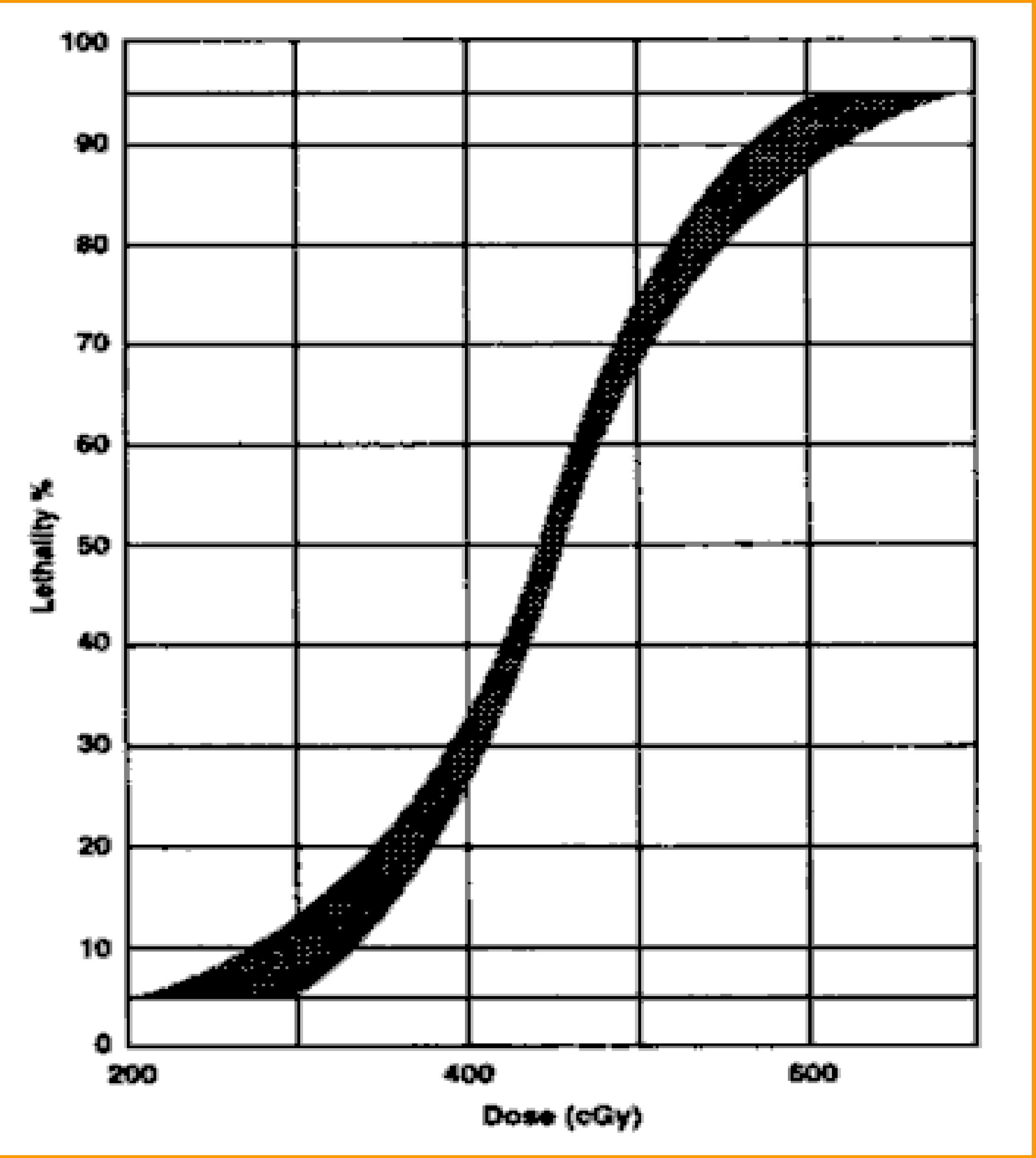
Linear energy transfer (LET): amount of energy deposited per unit track length

Acute Radiation Syndrome

- Signs and symptoms experienced by individuals exposed to acute whole body irradiation.
- Data collected largely through Japanese atomic bomb survivors at Hiroshima and Nagasaki.
- Limited number of accidents at nuclear installations.
- Clinical radiotherapy.
- Well-characterized animal data base.
- LD_{50} dose of human is ~4.5 Gy.
- Lethal Dose is $\geq$ 8 Gy

Human lethality as function of Dose

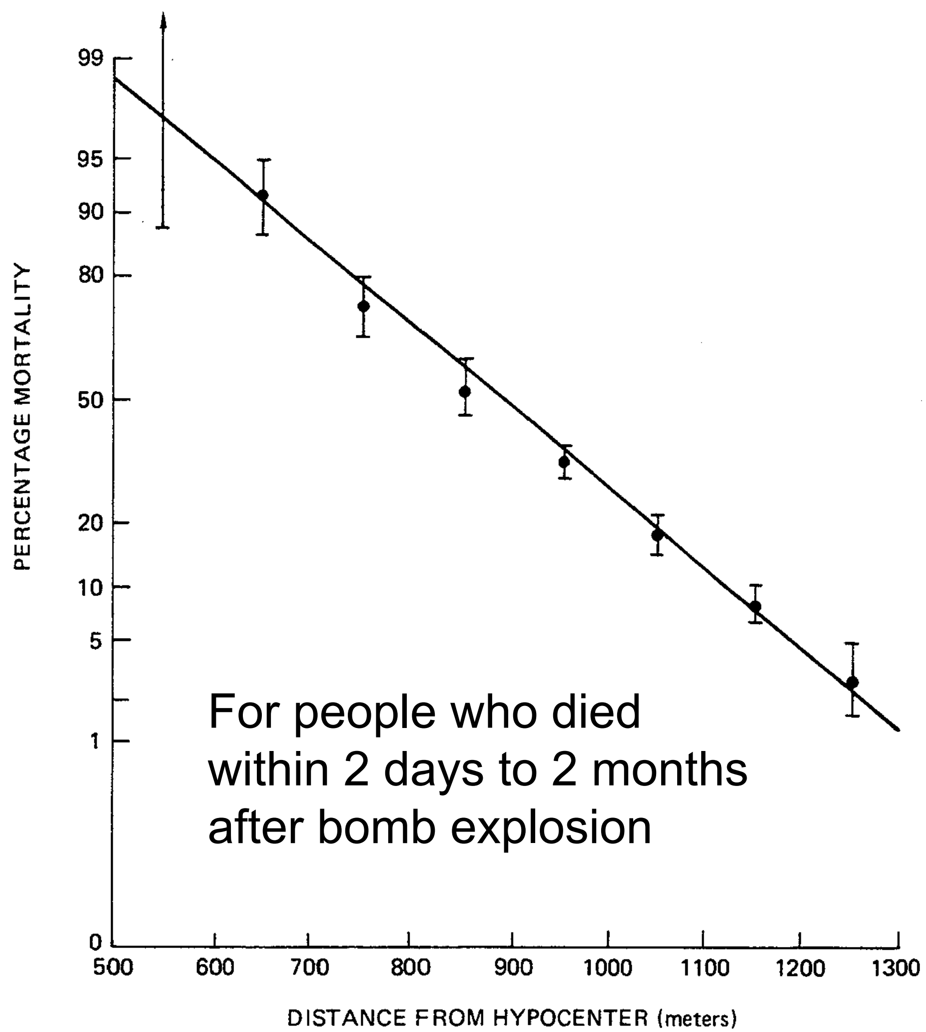
A 50% lethality
is reached at
an accumulated
dose of 450 cGy
=450 rad=4.5 Gy.
A 100 rad dose
is survivable.
A 800 rad dose is
lethal.



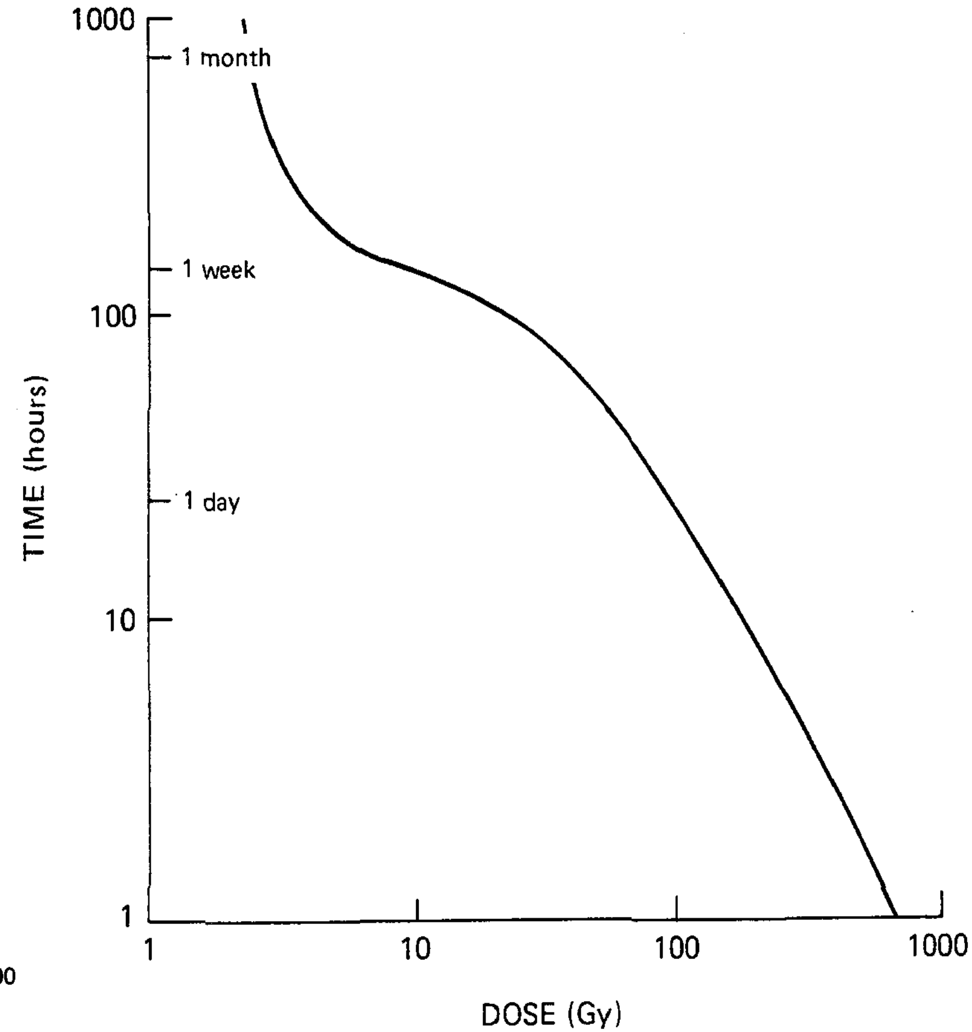
Prodromal Radiation Syndrome

- Early symptoms that appear after exposure to whole body radiation:
  - gastrointestinal: nausea, vomiting, diarrhea, anorexia
  - neuromuscular: easy fatigability
- Effect is dose dependent:
  - Varies in time of onset
  - Severity
  - Duration

Survival Chance

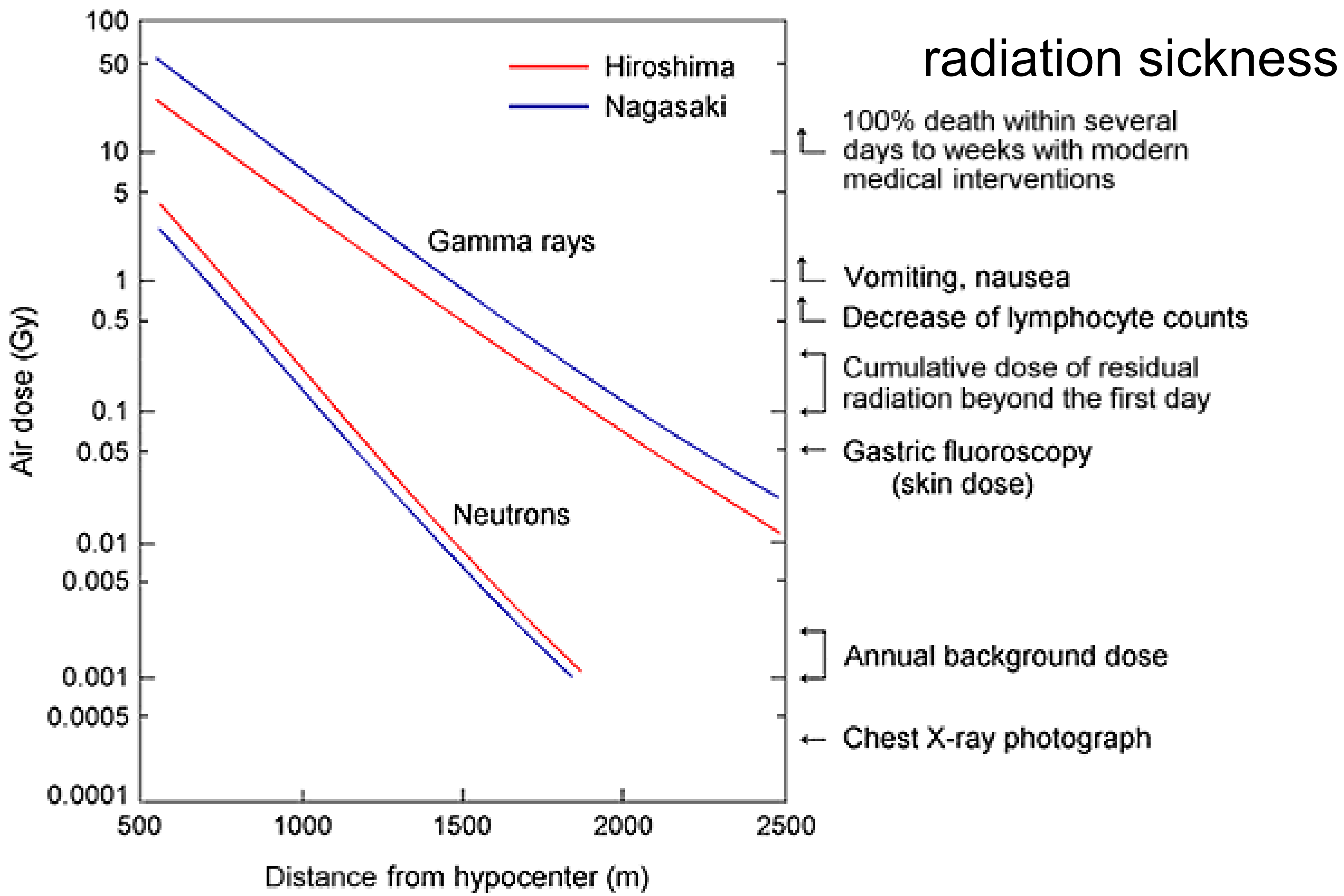


Probability of death as a function of distance from the hypocenter.



Time of occurrence of death from acute radiation effects.

Radiation Side Effects



Early Lethal Effects

Hematopoietic syndrome:

- Cause of death at doses <8 Gy.
- Peak incidence of death occurs at about 30 days post-irradiation, and continues for up to 60 days.
- Suppresses normal bone marrow and spleen functions.
- Symptoms associated with hematopoietic syndrome are: chill, fatigue, hemorrhages, ulceration, infection and anemia. Death usually result unless receive bone marrow transplant.

Early Lethal Effects

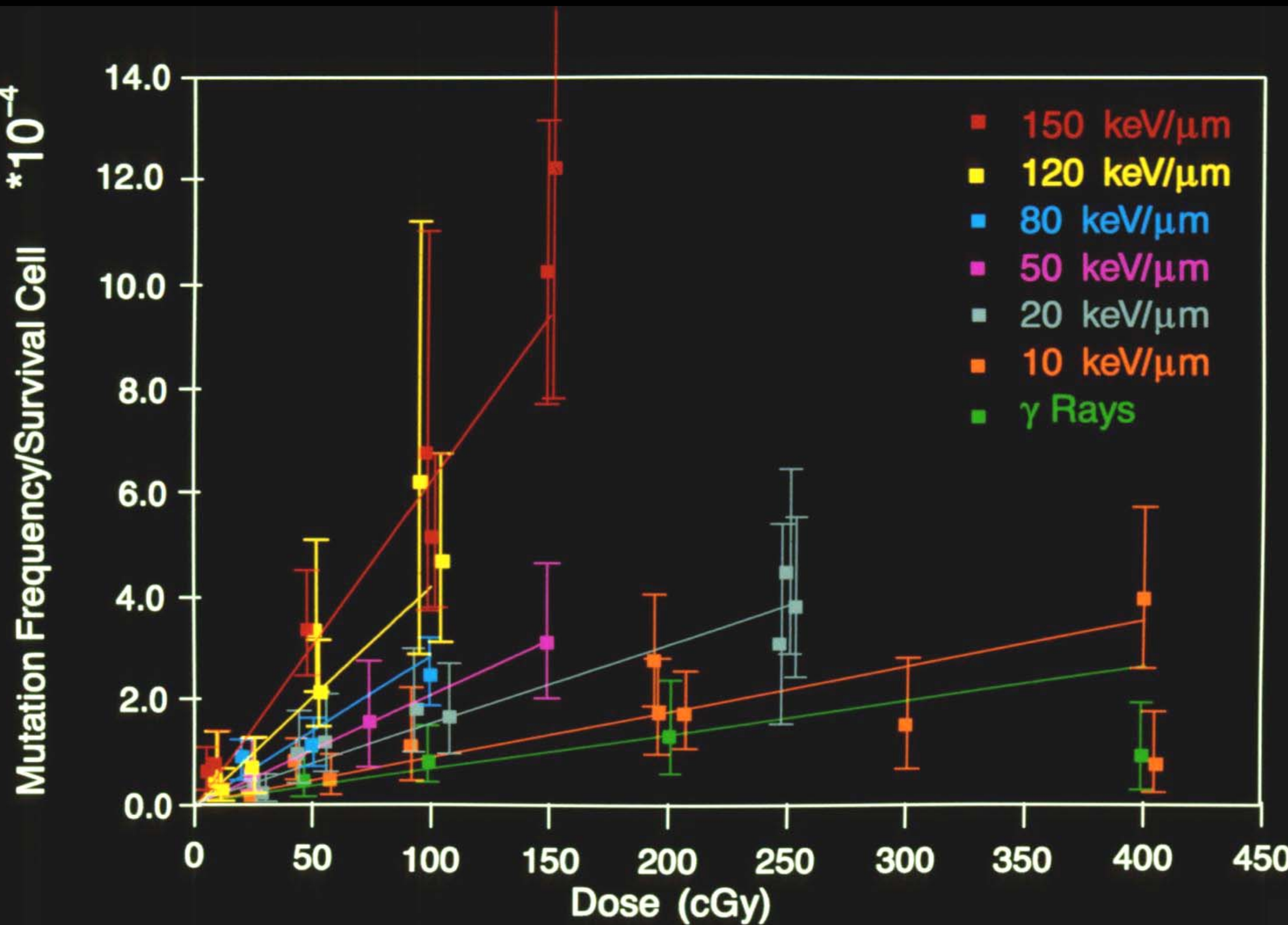
Gastrointestinal syndrome:

- Occurs at dose >10 Gy of gamma-rays or its equivalence.
- Death usually occurs within 3 to 10 days.
- Symptoms due largely to depopulation of the epithelial lining of the GI tract by radiation.
- No human has survived radiation dose >10 Gy.
- Clinical symptoms include nausea, vomiting, and prolong diarrhea, dehydration, loss of weight, complete exhaustion, and eventually death.

Early Lethal Effects

Cerebrovascular syndrome:

- Identified at doses >100 Gy of gamma-rays.
- Death occurs within hours from cardiovascular and neuromuscular complications.
- Clinical manifestations include severe nausea, vomiting within minutes of exposure, disorientation, loss of muscular co-ordination, respiratory distress, seizures, coma and death.

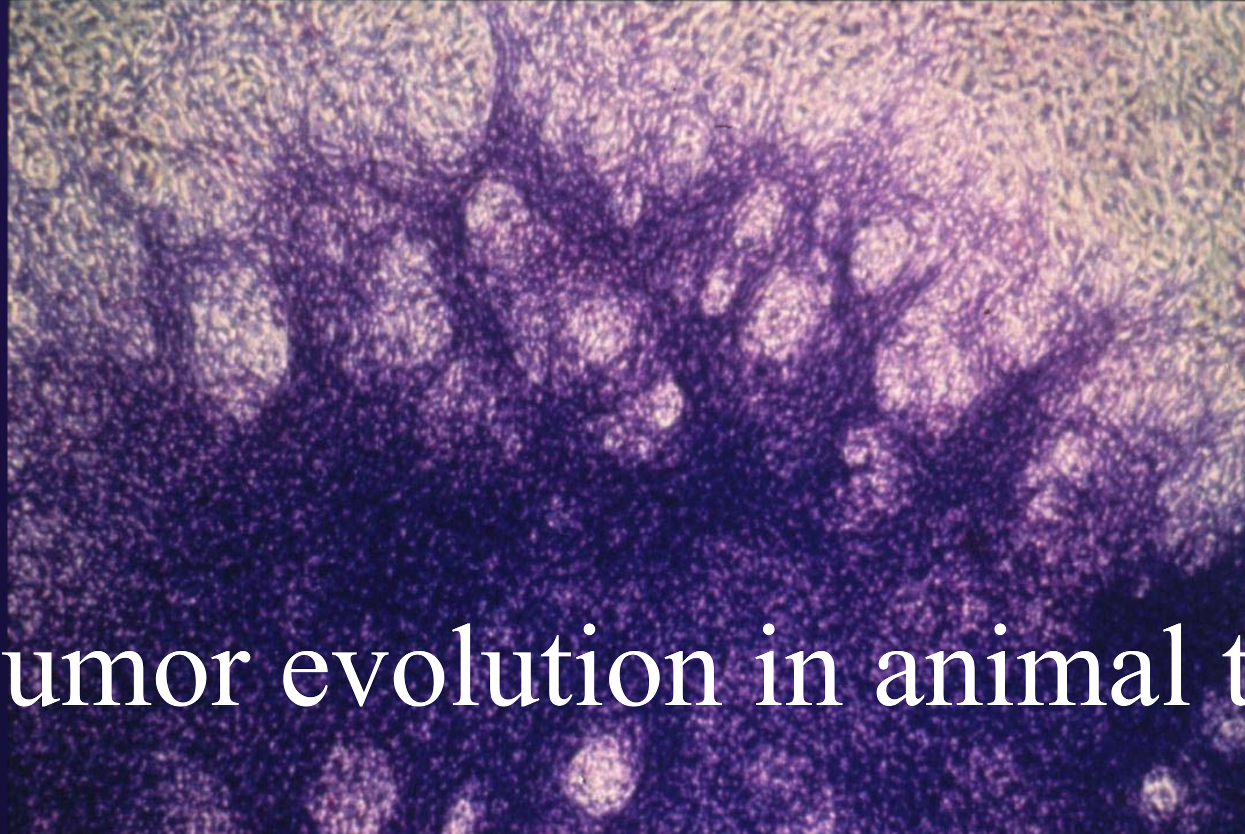


Mutation Frequency/Survival Cell *10^-4
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0
50
100
150
200
250
300
350
400
450
Dose (cGy)
150 keV/µm
120 keV/µm
80 keV/µm
50 keV/µm
20 keV/µm
10 keV/µm
γ Rays

Radiation-induced Mutagenesis

- Radiation *DOES NOT* produce new, unique mutations, but increases the incidence of the same mutations that occur spontaneously.
- Mutation incidence in humans is *DOSE* and *DOSE-RATE* dependent.
- A dose of 1 rem (10 mSv) per generation increases background mutation rate by 1%.
- Information on the genetic effects of radiation comes almost entirely from animal and *IN VITRO* studies.
- Children of A-bomb survivors from Hiroshima and Nagasaki fail to show any significant genetic effects of radiation.

Tumor evolution in animal tests



Radiation Carcinogenesis

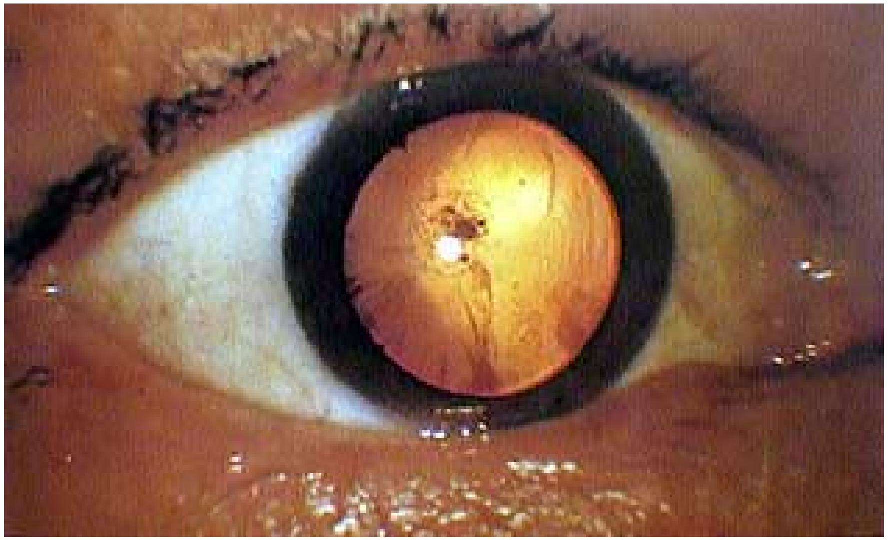
- A stochastic late effect.
- No threshold, an all or none effect.
- Severity is not dose related.
- Probability of carcinogenesis is dose dependent.
- Leukemia has the shortest latency period of ~5 years. Solid tumors have a latency period of ~20 to 30 years.
- Total cancer risk for whole body irradiation is one death per 10^4 individuals exposed to 1 rem.

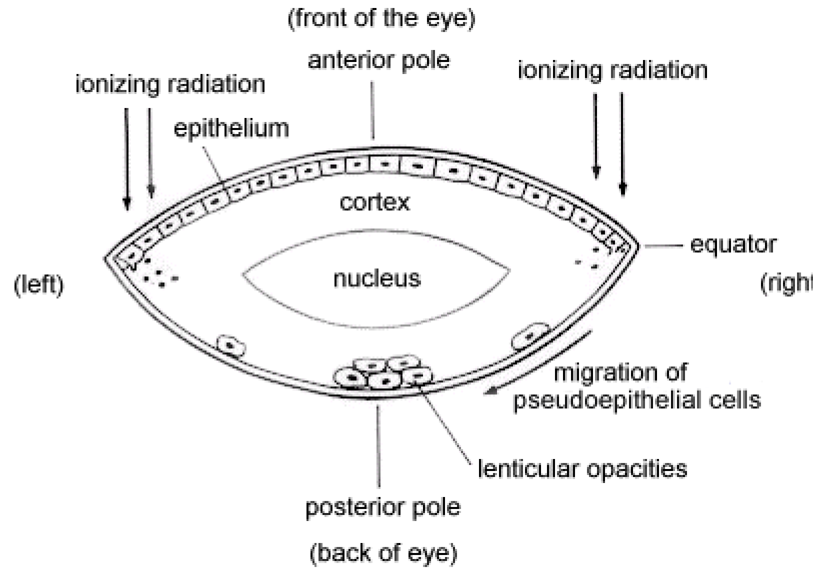
Nagasaki Effects

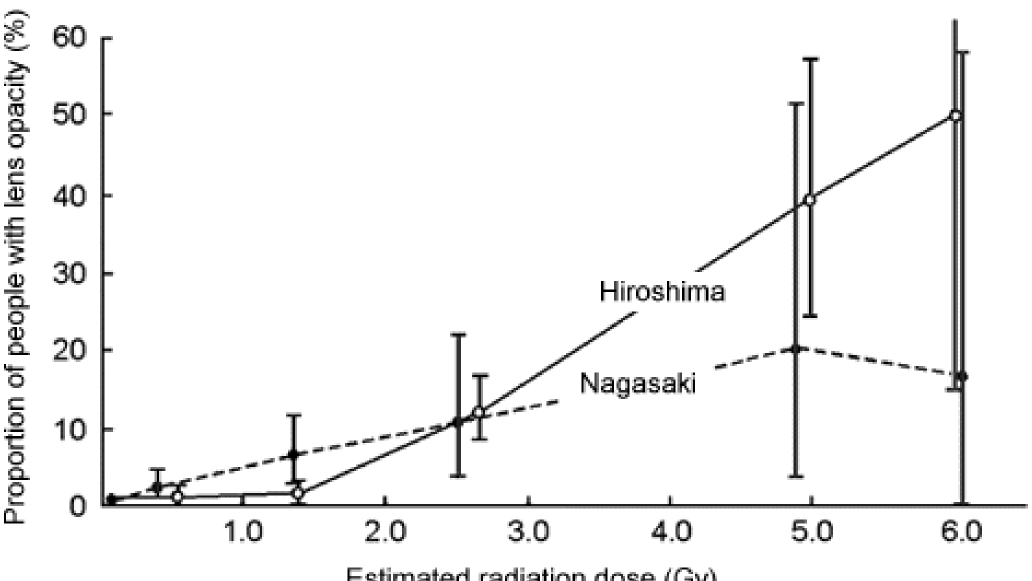
Purpura, Vomiting, …

Purpura, or bleeding under the skin, is one of the symptoms of acute radiation sickness. The heavily exposed survivors experienced fever, nausea, vomiting, lack of appetite, bloody diarrhea, epilation, purpura, sores in their throat or mouth (nasopharyngeal ulcers), and decay and ulceration of the gums about the teeth (necrotic gingivitis). The time of onset of these symptoms depends on the exposure level.

Long term effects - blindness



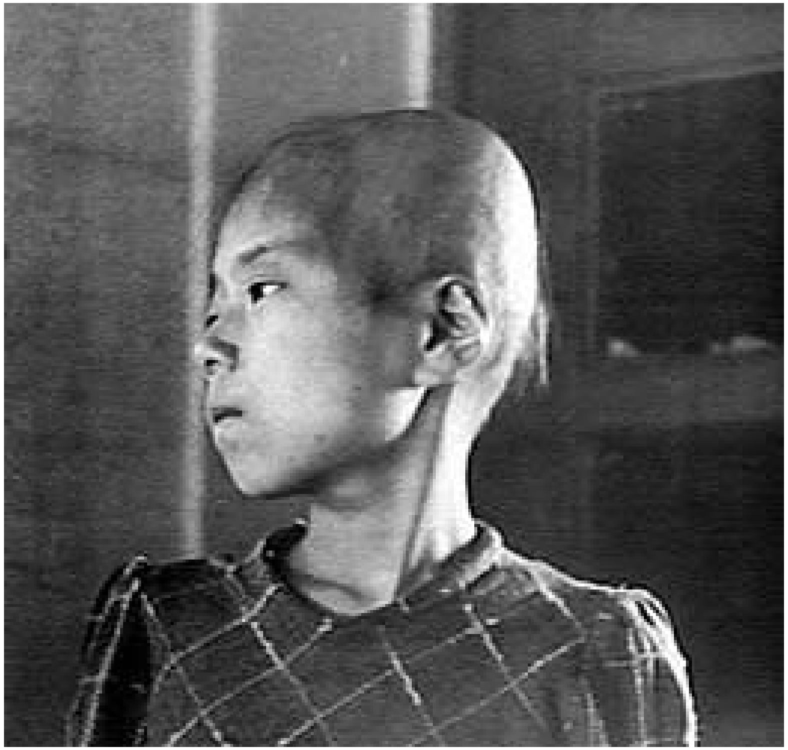




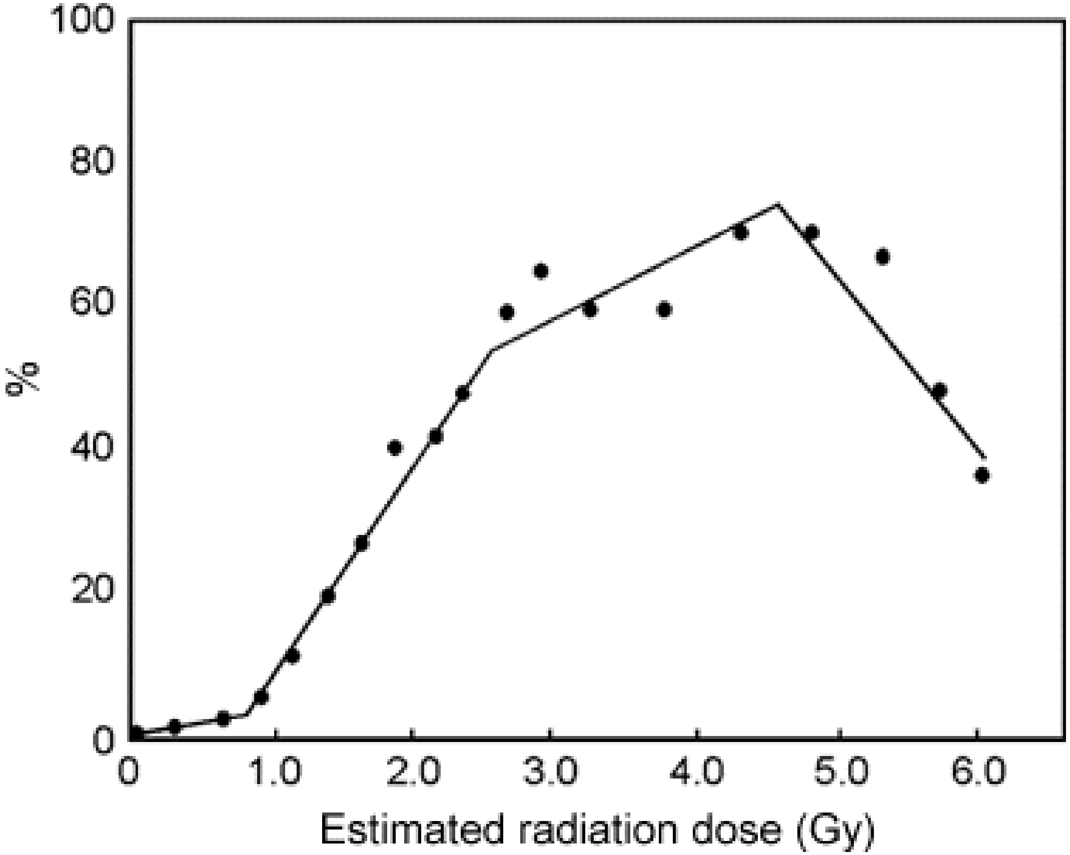
Radiation damage to epithelial Cells. Damaged cells move to the back of the eye and cause lens opacity by blocking light. Occurs with 50% chance for people with dose of ~500 rad.

Epilation – severe loss of hair

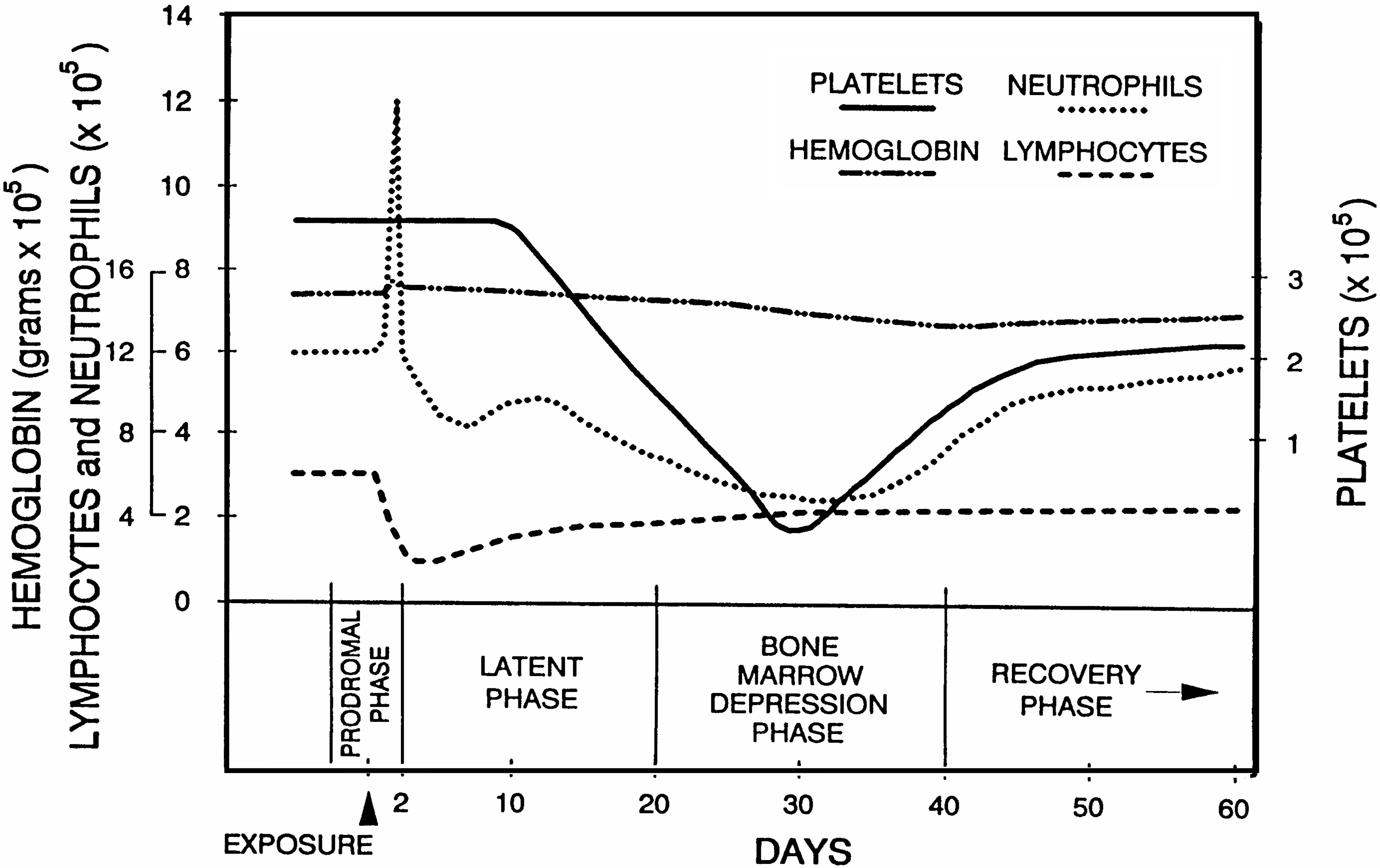
Hair loss is a common sign of radiation exposure & sickness.
Severe epilation (2/3 hair loss) occurs at doses of >200 rad.



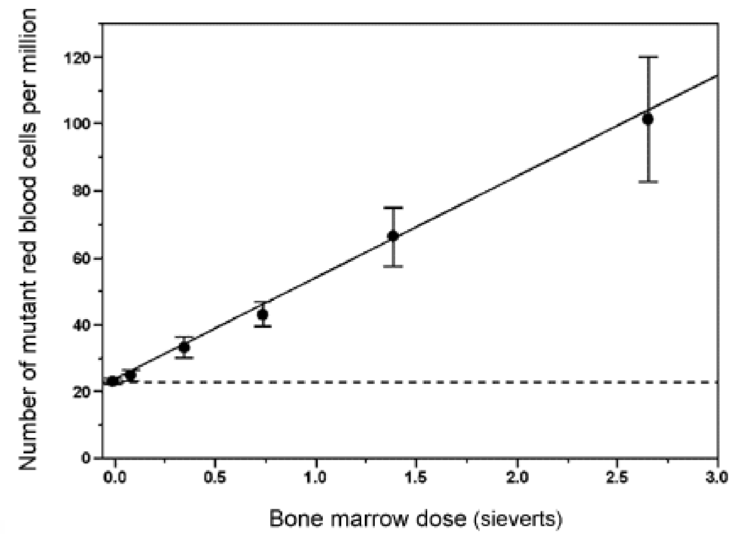
2km from hypocenter



Hemogram
blood impact of 300 rad exposure

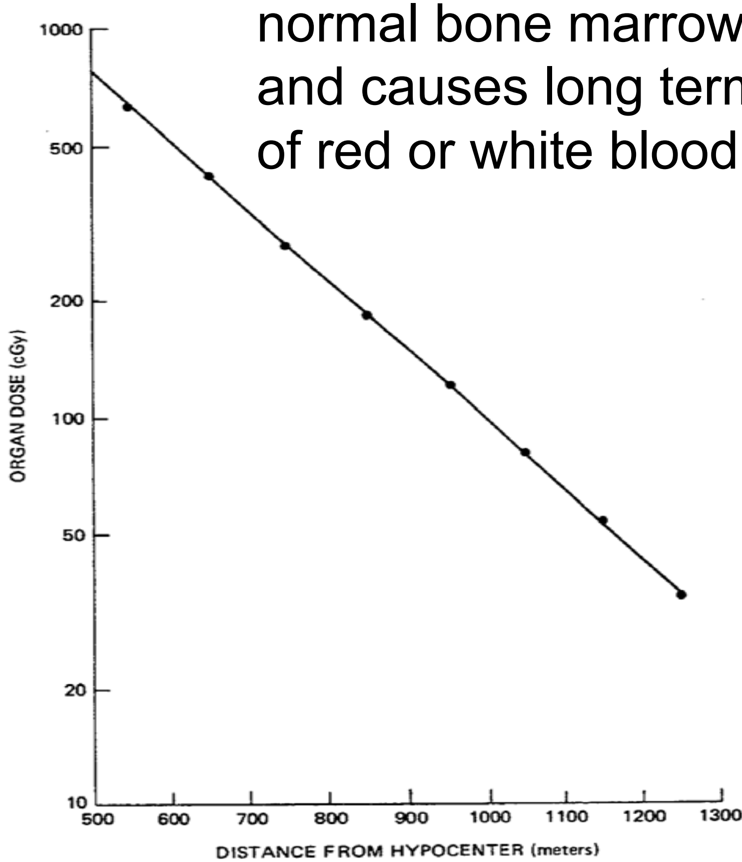


Radiation impact on bone marrow

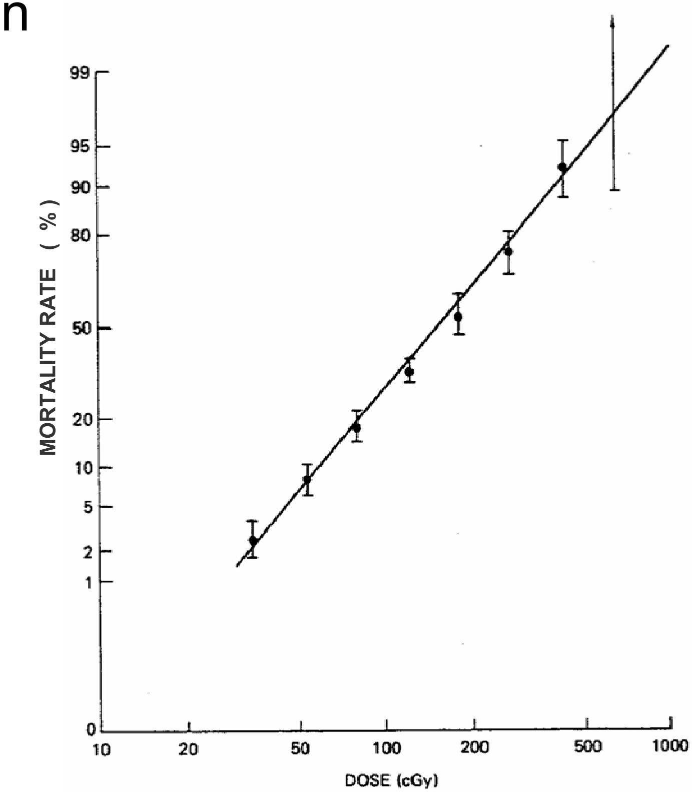


100 rad = 1 Gy ≈ 1 Sv

Radiation >2 Gy suppresses normal bone marrow functions and causes long term mutation of red or white blood cells



Bone marrow dose versus distance from hypocenter in the Hiroshima survey group.

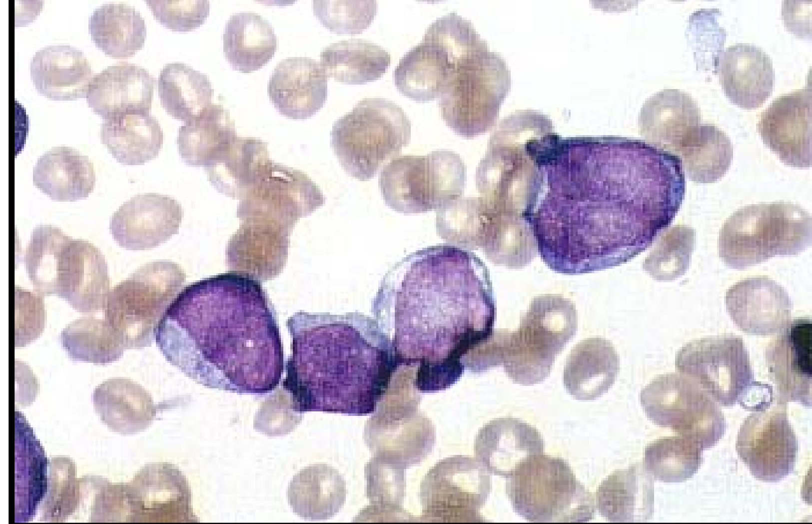


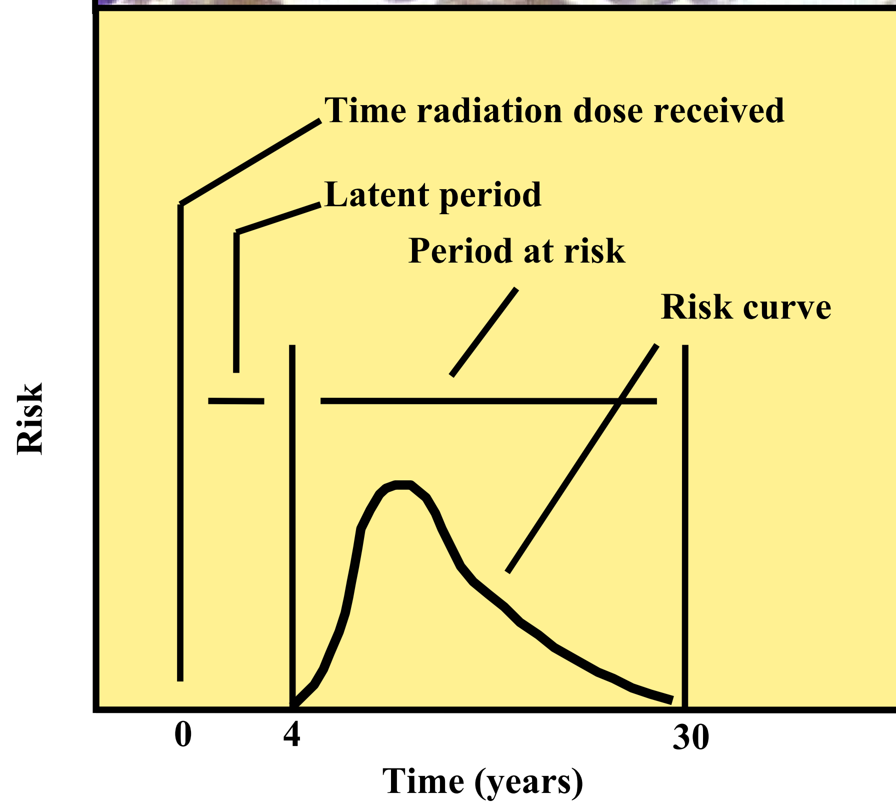
Percent mortality versus bone marrow dose in the Hiroshima survey

Leukemia

When leukemia develops, the body produces large numbers of abnormal blood cells. In most types of leukemia, the abnormal cells are white blood cells.

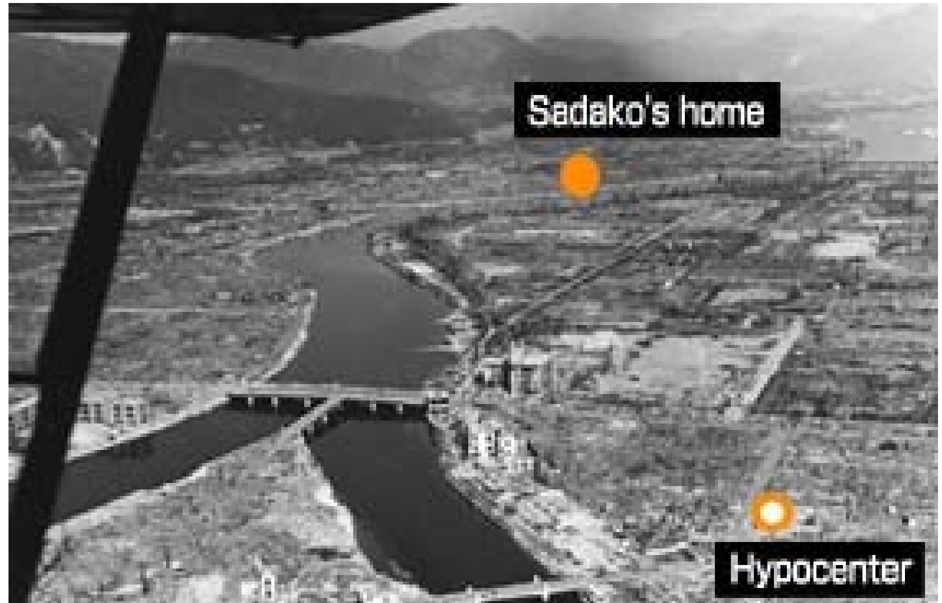
An increase in the number of leukemia cases was first noted in the late 1940s. As of 1990, there were 176 leukemia deaths among 50,113 survivors with significant exposures (>0.5Gy). It is estimated that about 90 of these deaths are associated with radiation exposure.

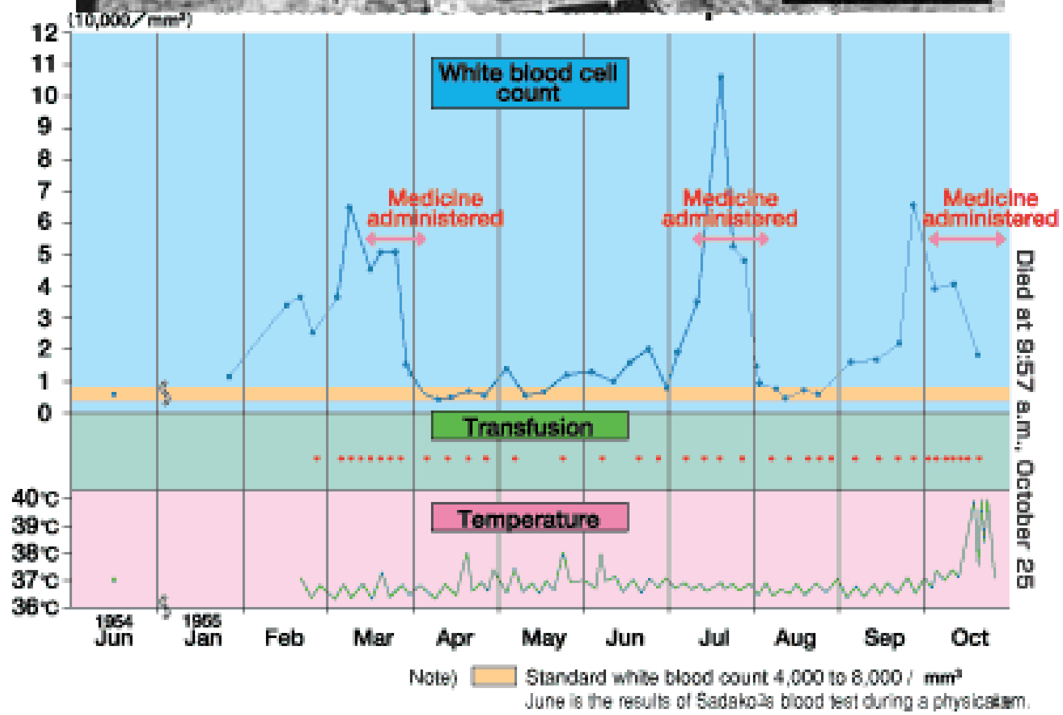




Leukemia Latency and Time at Risk Periods

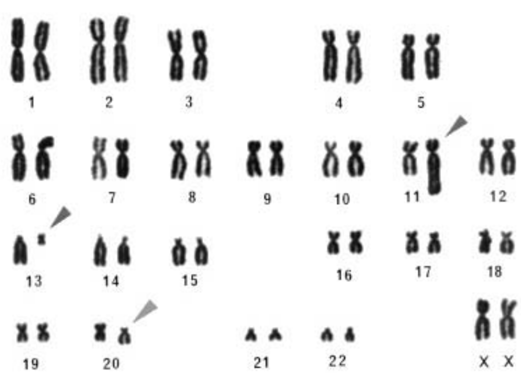
Leukemia – case of Sadako

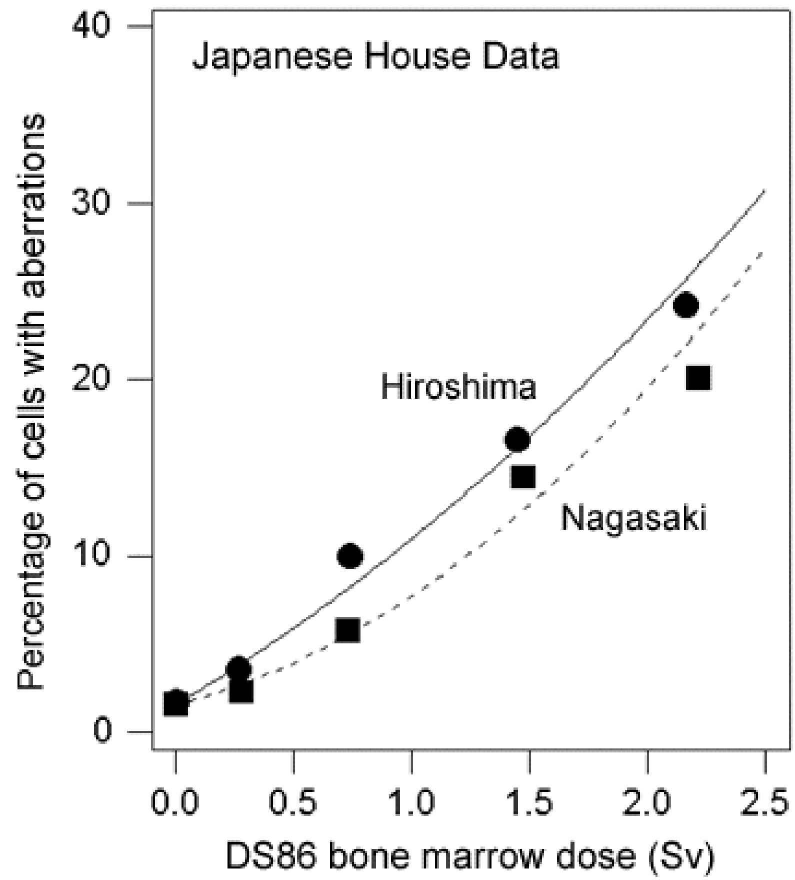




Long range genetic effects

Chromosomes observed during cell division. Abnormal ones are marked by grey arrow.



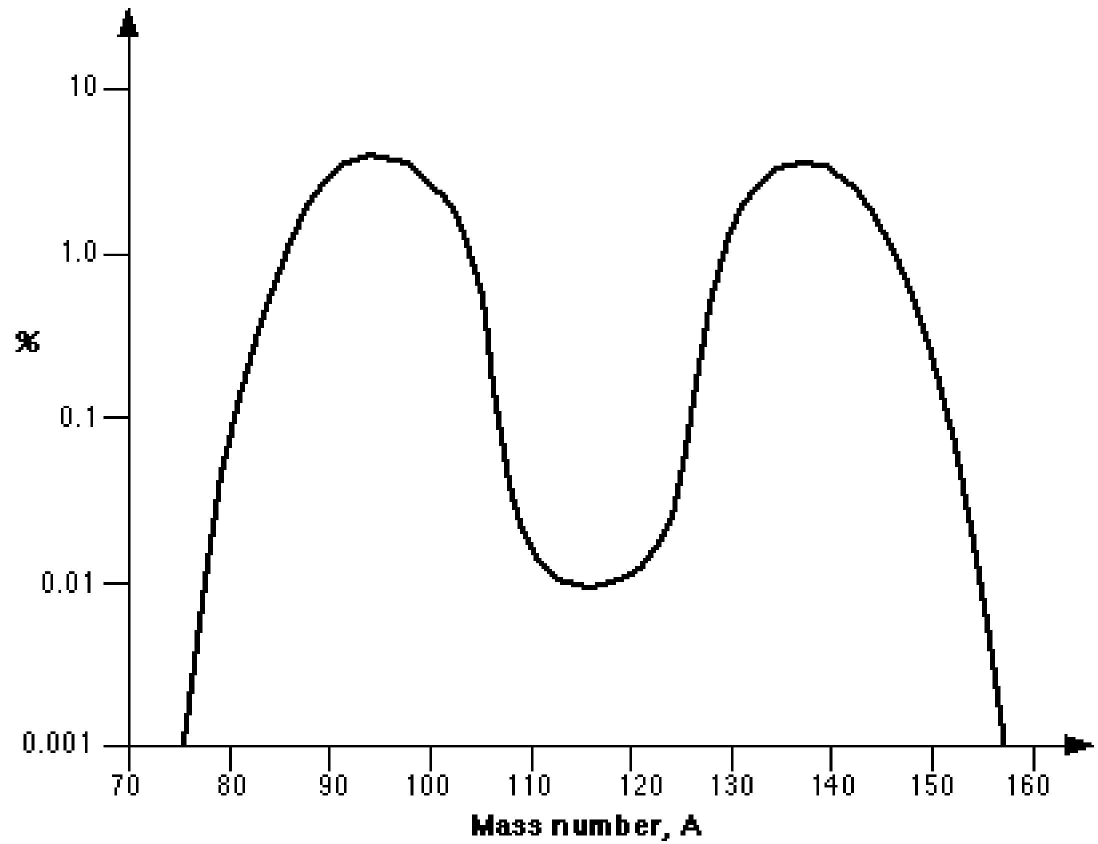


Observed increase with dose indicates long term genetic effects

Radiation Fallout

Delayed Radiation - Fallout

Fission of ^{235}U or ^{239}Pt generates a whole range of long-lived radioactive isotopes in the medium mass range A ≈ 80-160. There are about 40 ways of fission which produce ~ 80 radioactive species. These isotopes produce new radioactive isotopes by subsequent decay processes.



Isotopes of special importance

Especially dangerous are ^{131}I, ^{89}Sr, ^{90}Sr, and ^{137}Cs. This is due to both their relative abundance in fallout, and to their special biological affinity.

^{131}I is a β and γ emitter with a half-life of 8.07 d (specific activity 124,000 Ci/g) Its decay energy is 606 keV β, 364 keV γ. It constitutes some 2% of fission-produced isotopes - $1.6 \cdot 10^5$ Ci/kiloton. Iodine is readily absorbed by the body and concentrated in one small gland, the thyroid.

^{90}Sr is a β emitter (546 keV, no γ) with a half-life of 28.1 years (specific activity 141 Ci/g), **^{89}Sr** is a β emitter (1.463 MeV, γ very rarely) with a half-life of 52 d (specific activity 28,200 Ci/g). Each constitutes about 3% of total fission isotopes: 190 curies of ^{90}Sr and 3.8×10^4 curies of ^{89}Sr per kiloton. Due to their chemical resemblance to calcium these isotopes are absorbed and stored in bones. ^{89}Sr is an important hazard for a year or two after an explosion, but ^{90}Sr remains a hazard for centuries. Actually most of the injury from ^{90}Sr is due to its daughter isotope **^{90}Y** which has a half-life of only 64.2 h, so it decays as fast as it is formed, and emits 2.27 MeV β particles.

^{137}Cs is a β and γ emitter with a half-life of 30.0 y (specific activity 87 Ci/g). Its decay energy is 514 keV β, 662 keV γ. It comprises some 3-3.5% of total fission products - 200 Ci/kT. It is the primary long-term gamma emitter hazard from fallout, and remains a hazard for centuries.

The Military's Point of View in the 1950^{ties}

Short distance radioactive fall out

The fission of 57 grams of material produces $3 \cdot 10^{23}$ atoms of fission products (two for each atom of fissionable material). One minute after the explosion this mass is undergoing decays at a rate of 10^{21} disintegrations/sec ($3 \cdot 10^{10}$ curies). It is estimated that if these products were spread over 1 km^2, then at a height of 1 m above the ground one hour after the explosion the radiation intensity would be 7500 rad/hr. 1 kT bomb would correspond to $1.2 \cdot 10^{8}$ rad/h spread over 1 km^2, a person has a surface of $S \approx 1.9\ m^2 = 1.9 \cdot 10^{-6}\ km^2$, its exposure is 230 rad/h; for a 10 kT bomb, the exposure is 2300 rad/h or 38 rad/min.

Military Personal Tests

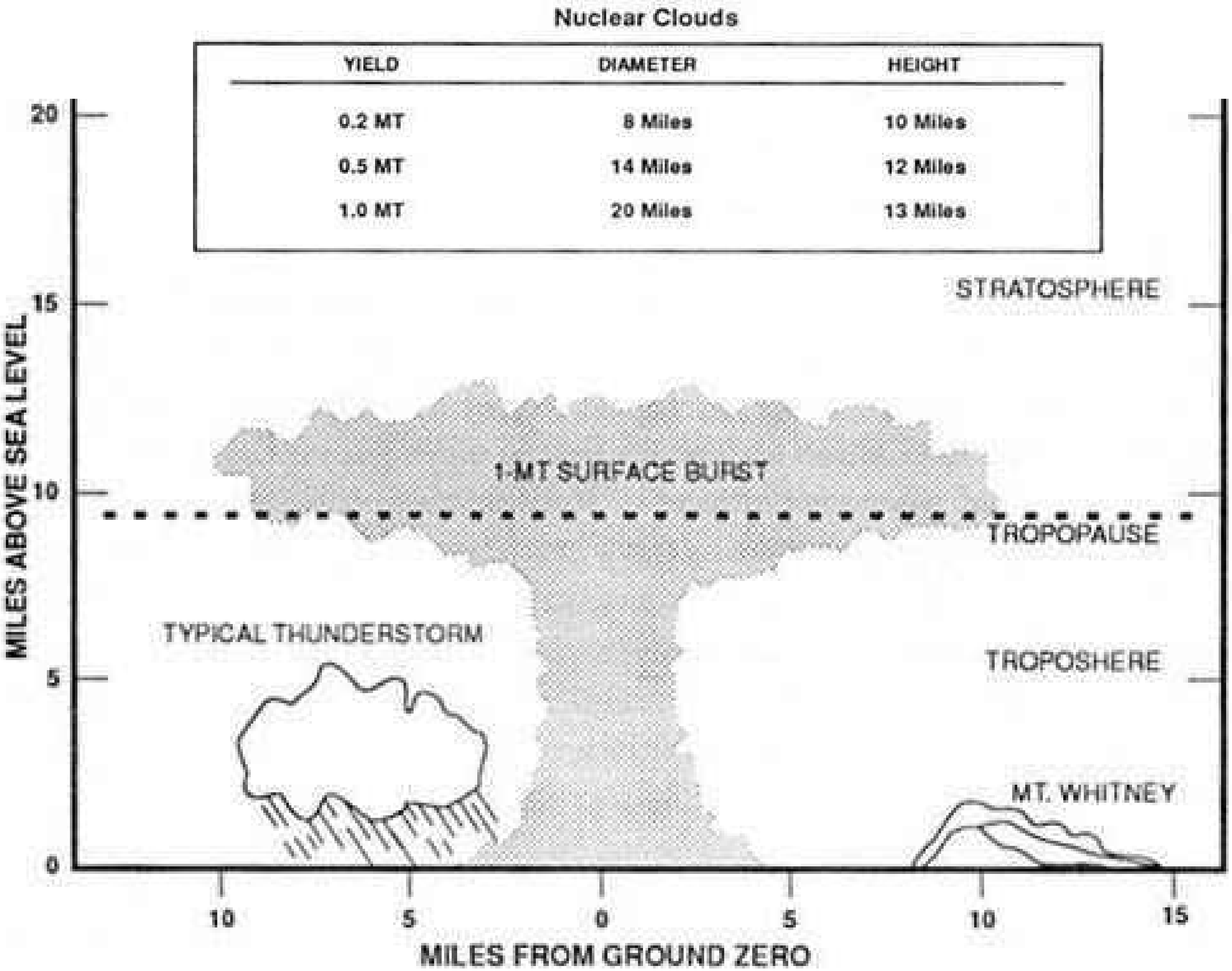
In 1951, every aspect of nuclear testing was controlled by the AEC. To get realistic results in atomic exercises, the military suggested that the men should be "stressed."

The military wanted the men to be placed closer to the atomic blasts to learn how to conduct atomic warfare on a future nuclear battlefield. To do that, the DOD would have to take control of personnel away from the AEC. By early 1953, the Pentagon had succeeded. When a nuclear test involved battlefield maneuvers, field commanders, would be responsible for the placement of their men near atomic detonations.

Military operations at nuclear bomb tests

Number of participants unclear: Radiation Exposure Compensation Program

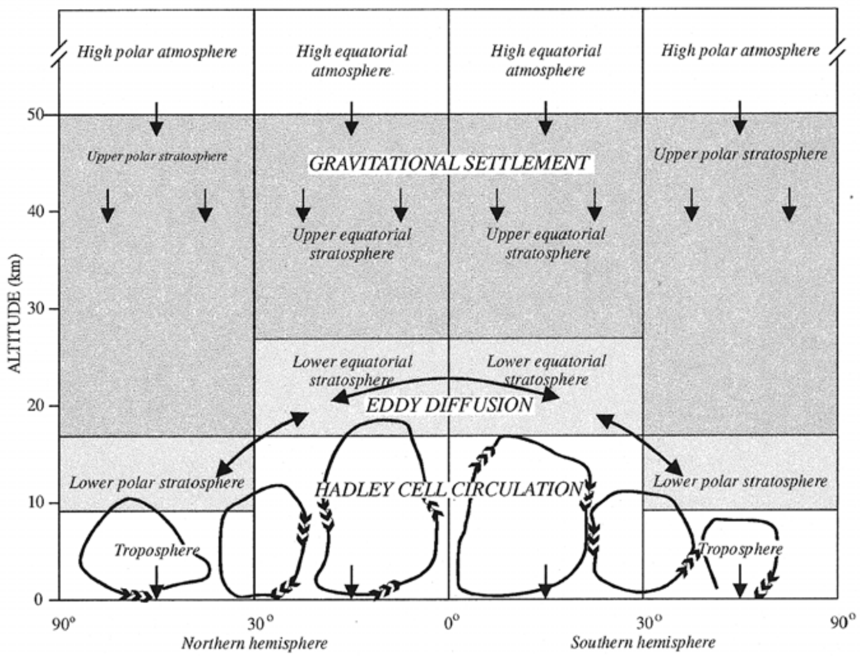
Emission into Stratosphere



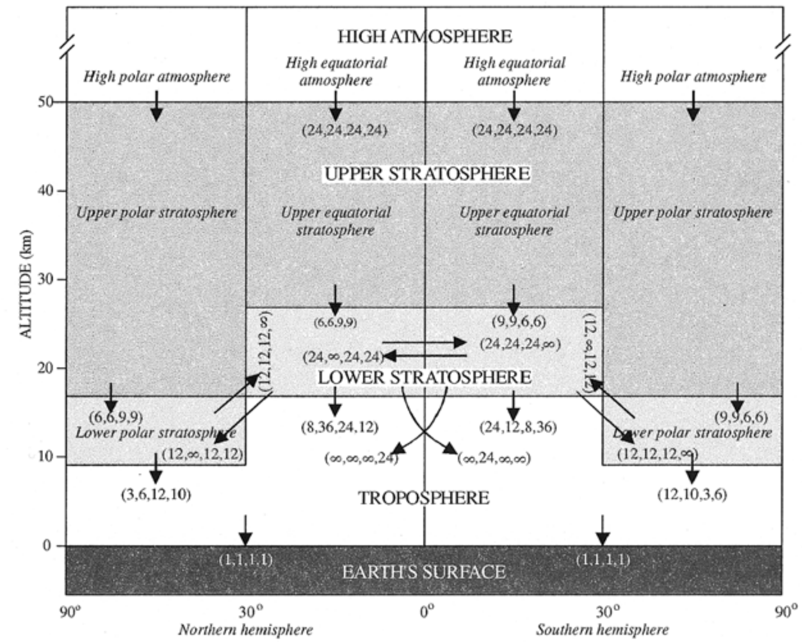
Nuclear Clouds

YIELD	DIAMETER	HEIGHT
0.2 MT	8 Miles	10 Miles
0.5 MT	14 Miles	12 Miles
1.0 MT	20 Miles	13 Miles

High Altitude Distribution



Atmospheric regions and the predominant atmospheric transport processes.

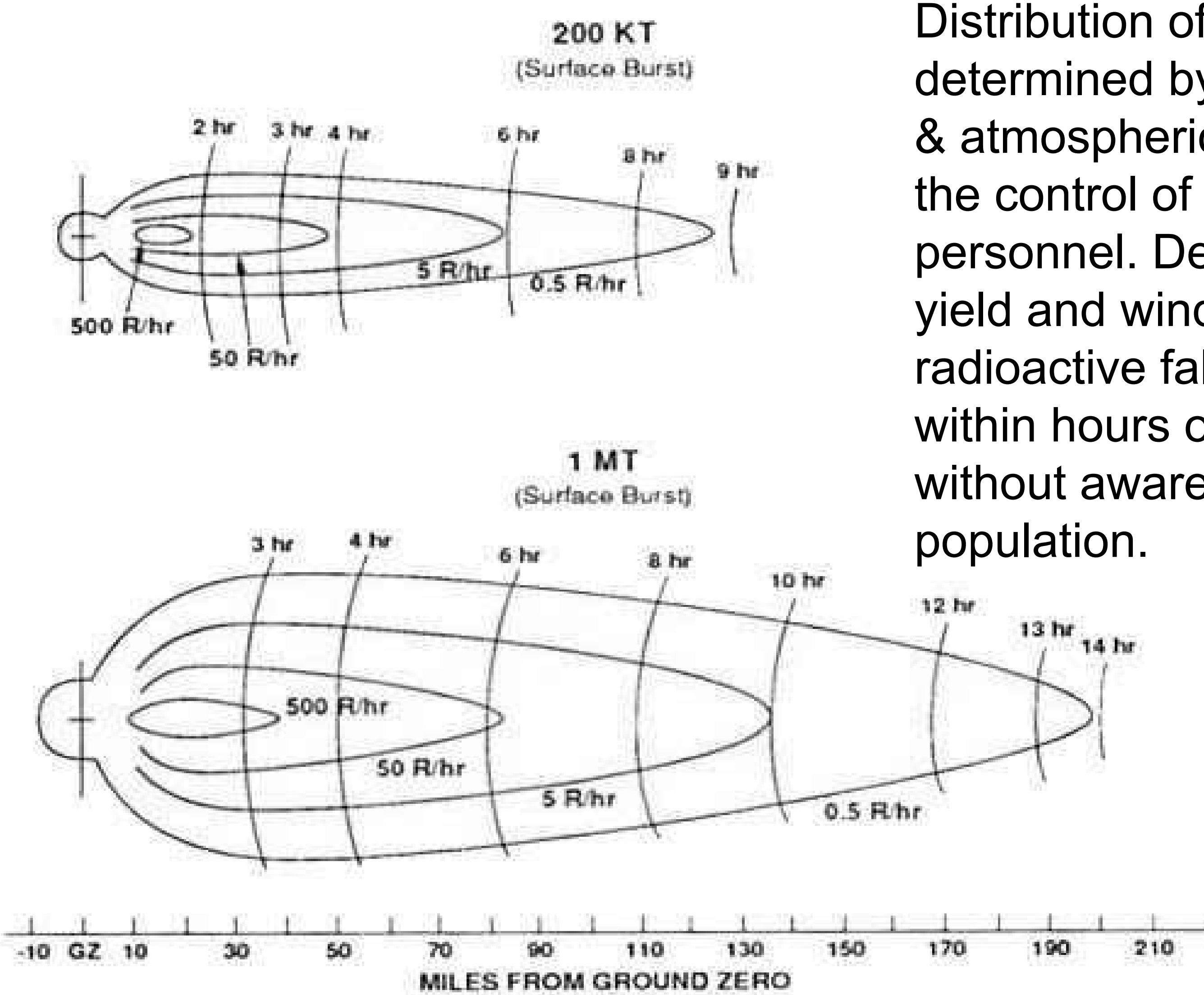


Schematic diagram of transfers between atmospheric regions and the earth's surface considered in the empirical atmospheric model [B1].

numbers in parentheses are the removal half-times (in months) for the yearly quarters in the following order: March-April-May, June-July-August, September-October-November, December-January-February.

Ejection of material into the troposphere and the lower stratosphere and re-distributed over polar (3-12 months) or equatorial regions (8-24 months) depending on magnetic field and gravitational conditions. Fall-out removal times (defined in terms of half-life) ranges from 10 to 24 months depending on seasonal conditions, most rapid during spring, slow in summer.

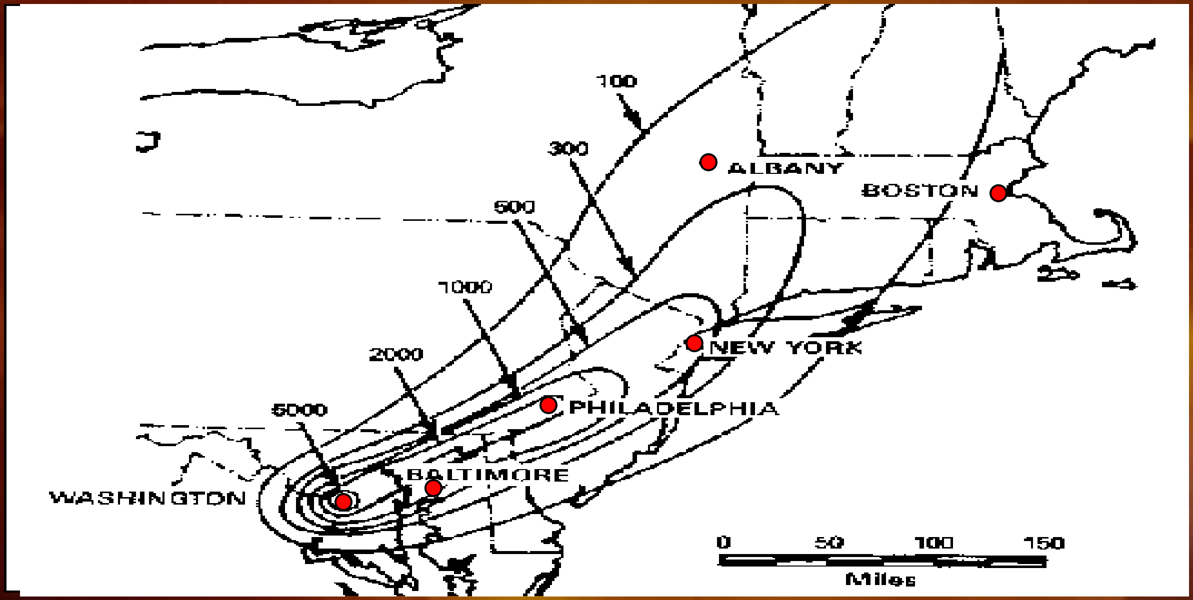
Fallout Patterns



Distribution of radioactivity is determined by high altitude wind & atmospheric conditions beyond the control of test conducting personnel. Depending on test yield and wind velocity (15mph) radioactive fallout is spread within hours over large distances without awareness of the local population.

Nearby Communities

Operation Castle 1953 - Bravo Test

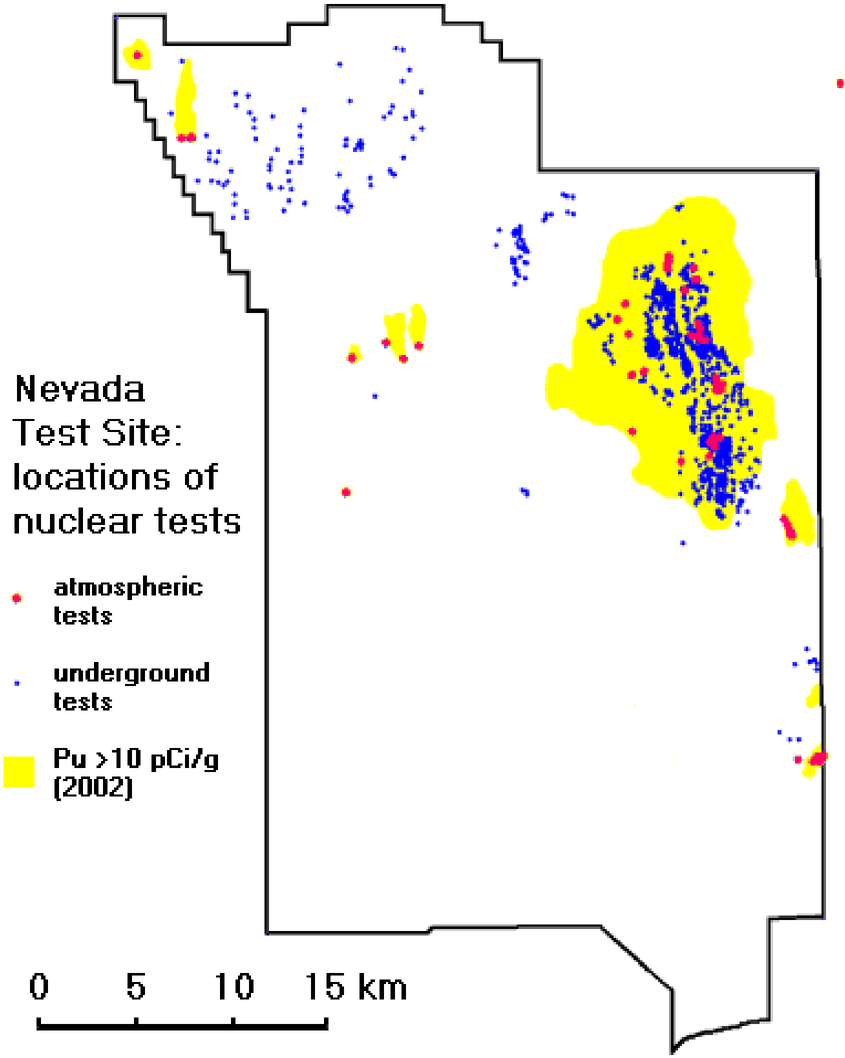


The Bravo test created the worst radiological disaster in US history. Due to a failure to postpone the test following unfavorable changes in the weather, combined with an unexpectedly high yield and the failure to conduct pre-test evacuations as a precaution, Marshallese Islanders on Rongerik, Rongelap, Ailinginae, and Utirik atolls were blanketed with the fallout plume. They were evacuated March 3 but 64 Marshallese received doses of 175 rad. In addition, the Japanese fishing vessel Lucky Dragon was also heavily contaminated, with the 23 crewmen receiving exposures of 300 rad - one of them later died.

Test Bravo Fall-Out

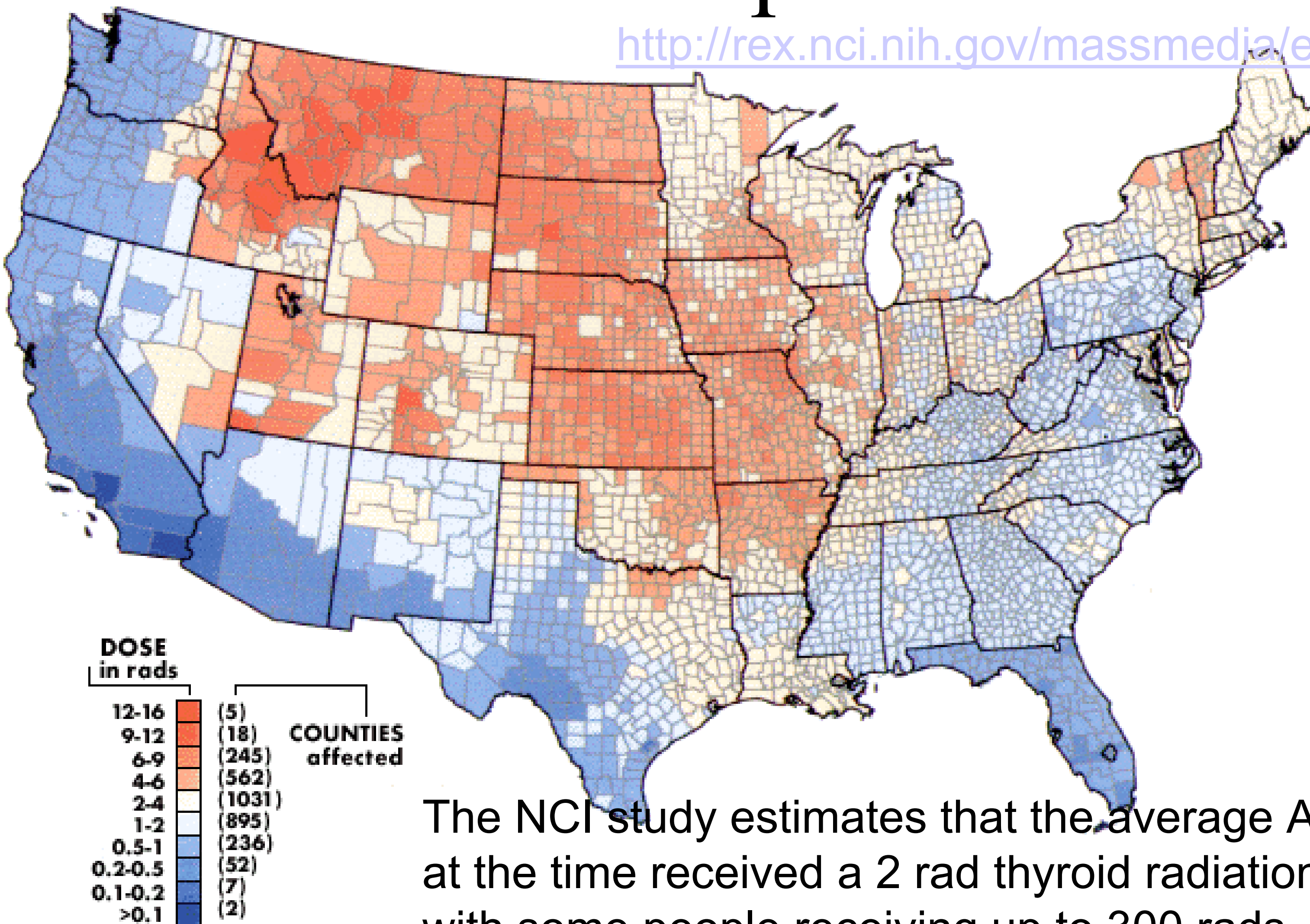
Atmospheric tests 1945-1963

Atmospheric bomb tests at the Nevada test site caused the production of large amounts of long-lived radioactivity in the atmosphere which was distributed by high altitude winds over the USA and Canada and even world wide. As shown in a study of the National Cancer Institute NCI 1997 internal exposures to radioiodine ^{131}I from fallout was the most serious health risk of continental nuclear testing. Radioiodine concentrates in milk when consumed by cows when grazing, and concentrates in human thyroid glands when contaminated milk is ingested.



Total fallout pattern for ^{131}I

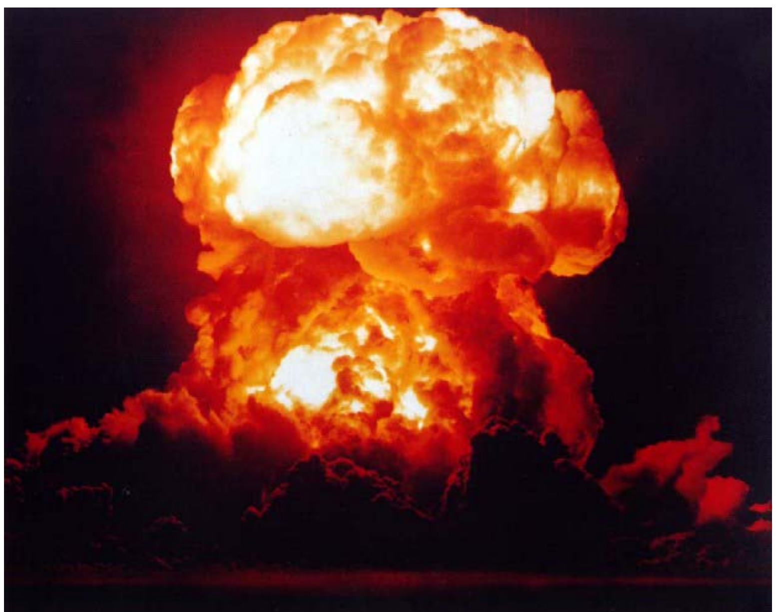
http://rex.nci.nih.gov/massmedia/exesum.html



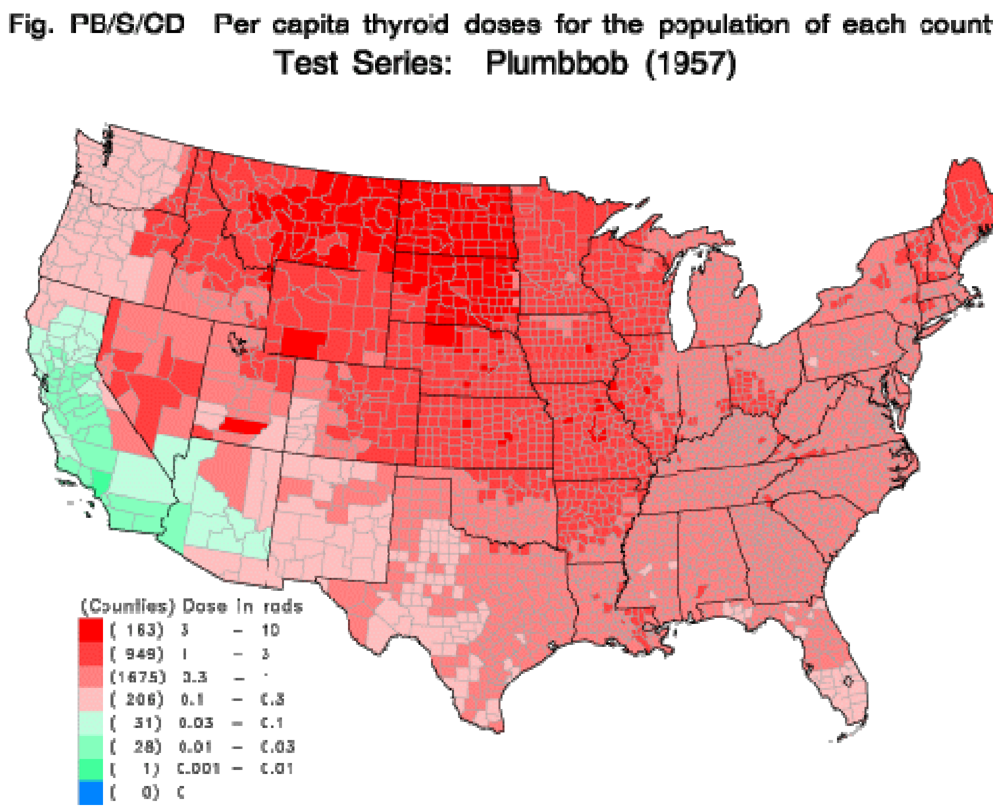
The NCI study estimates that the average American alive at the time received a 2 rad thyroid radiation exposure, with some people receiving up to 300 rads. It has been estimated that from 380 million person-rads of total exposure roughly 120,000 extra cases of thyroid cancer can be expected to develop, resulting in ~6,000 deaths.

Plumbbob 1957

The Plumbbob test series released ~ 58,300 kCi (~$2 \cdot 10^{18}$ Bq) of radioiodine (^{131}I) into the atmosphere. This was more than twice as much as any other continental test series. This produced total civilian radiation exposure amounting to 120 million person-rads of thyroid tissue exposure (about 32% of all exposure due to continental nuclear tests). This has been estimated to cause about 38,000 cases of thyroid cancer, leading to some 1900 deaths.

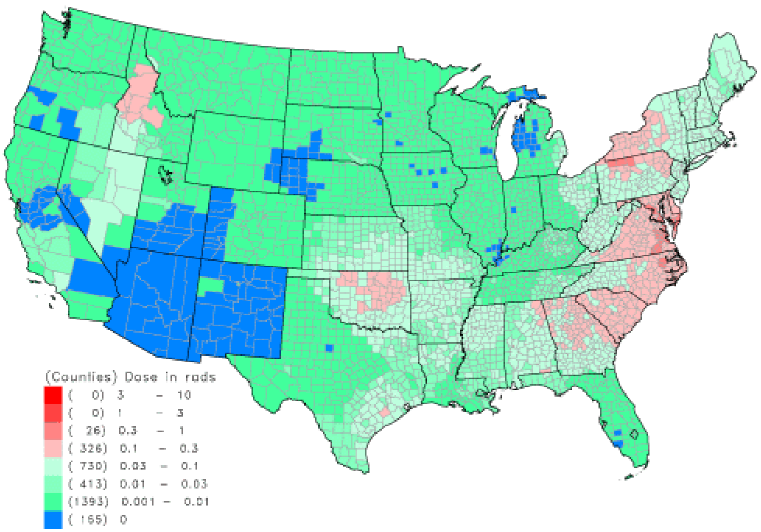


29 tests in 1957,
Nevada test site
16000 participants

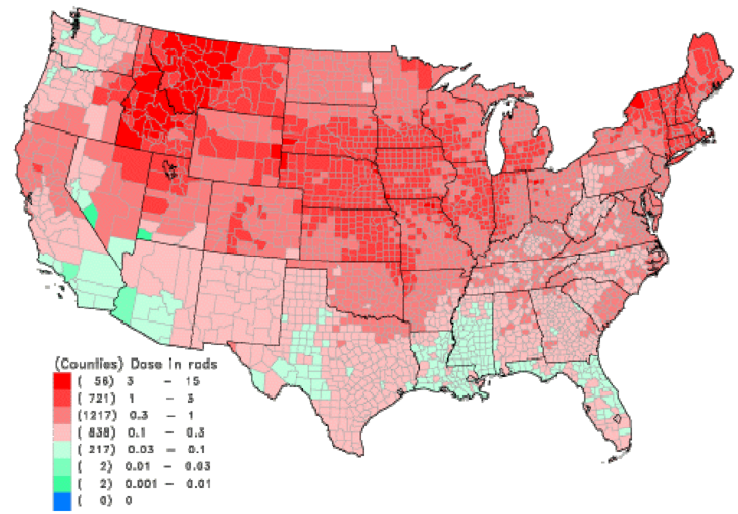


^{131}I Fallout from Nevada Tests

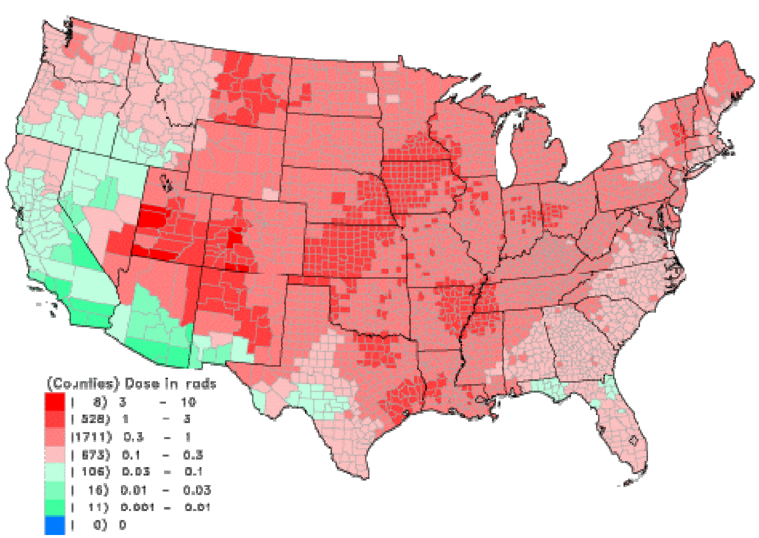
Per capita thyroid doses for the population of each county
Test Series: Buster-Jangle (1951)



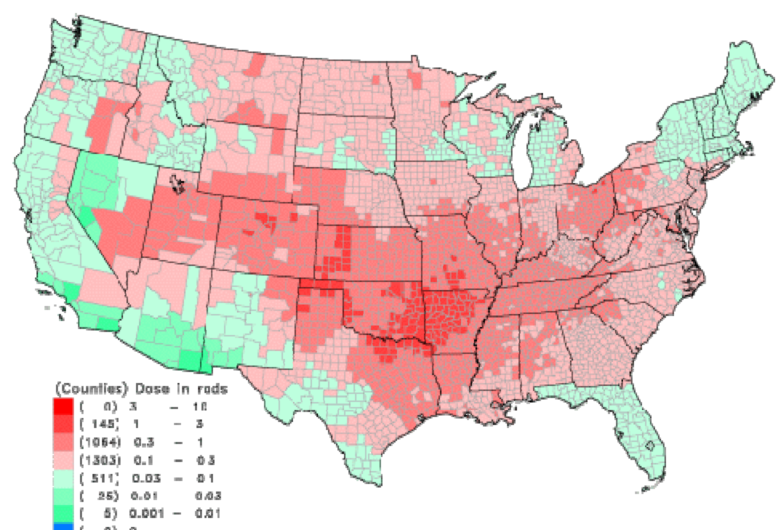
Per capita thyroid doses for the population of each county
Test Series: Tumbler-Snapper (1952)



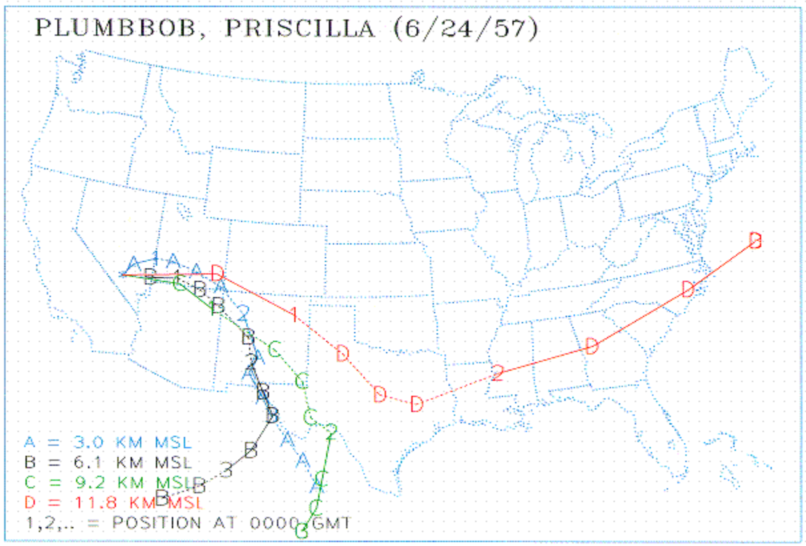
Per capita thyroid doses for the population of each county
Test Series: Upshot-Knothole (1953)

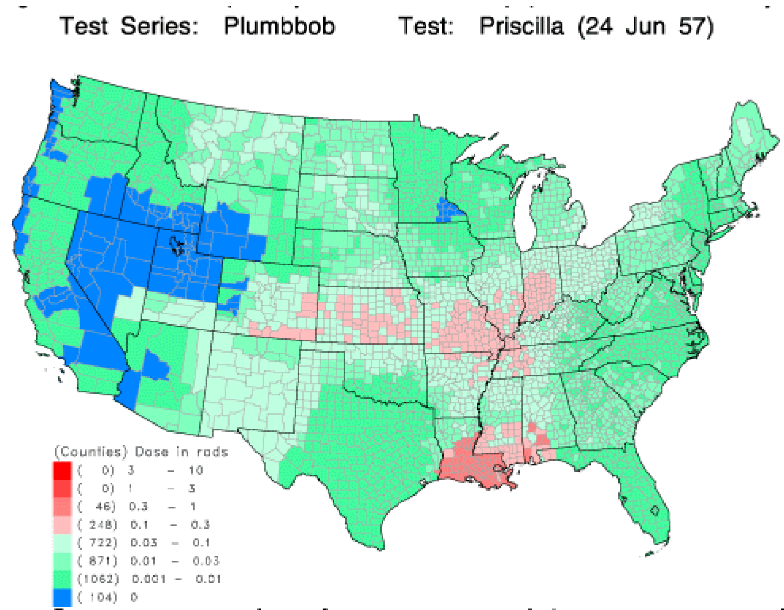


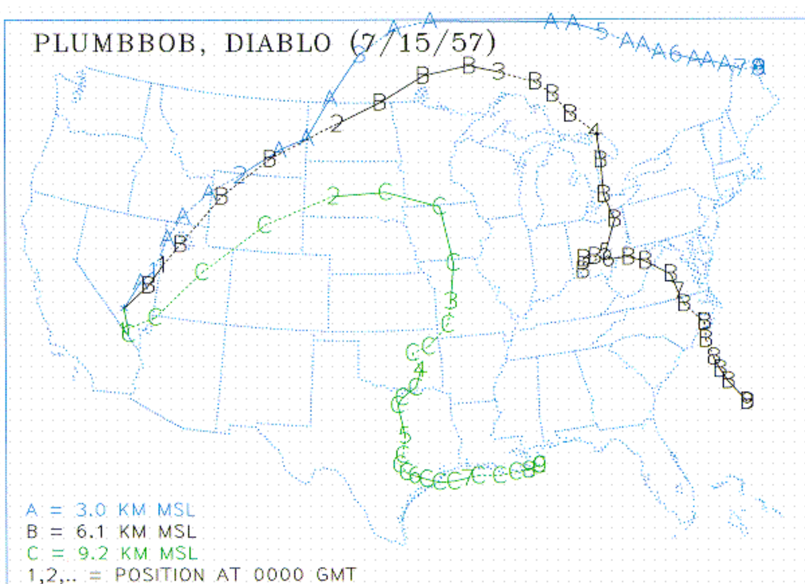
Per capita thyroid doses for the population of each county
Test Series: Teapot (1955)

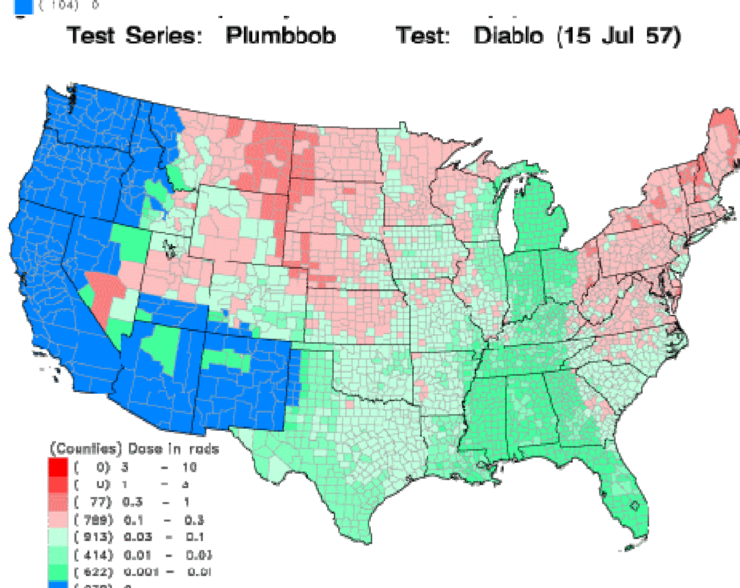


High altitude wind distribution of fallout from selected Plumbbob tests

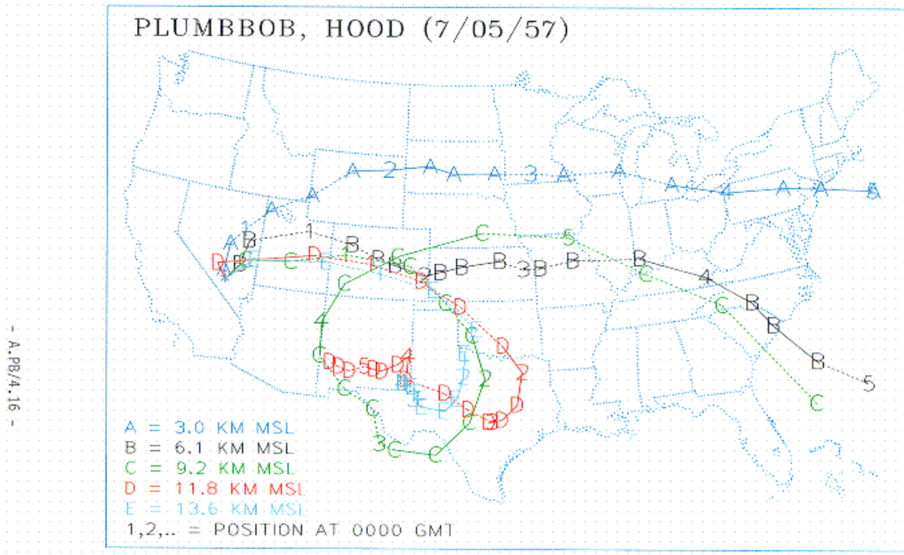


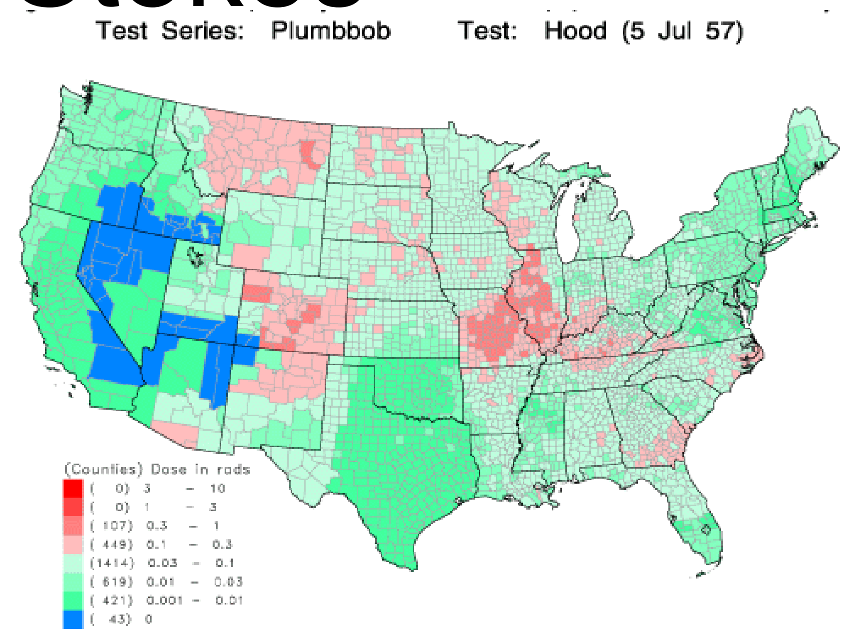


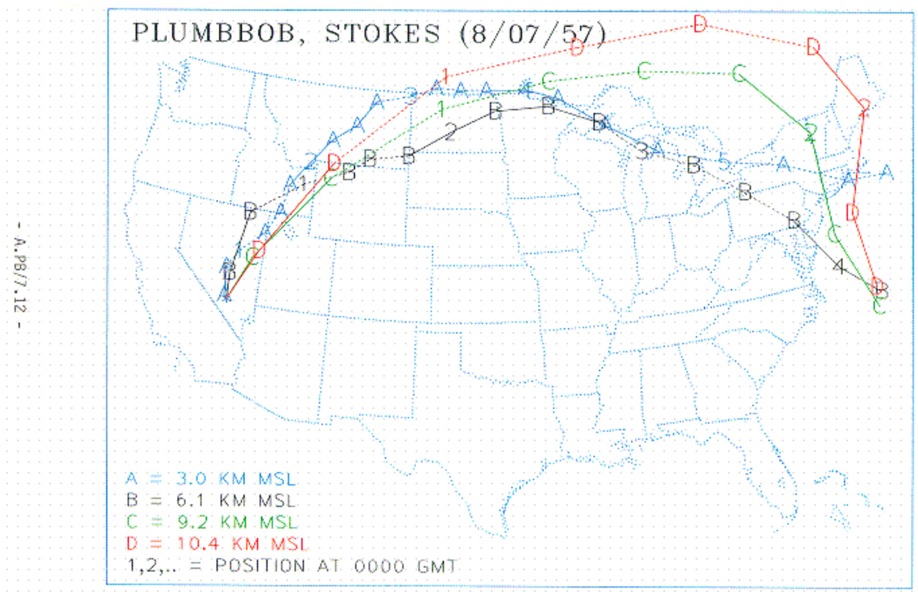


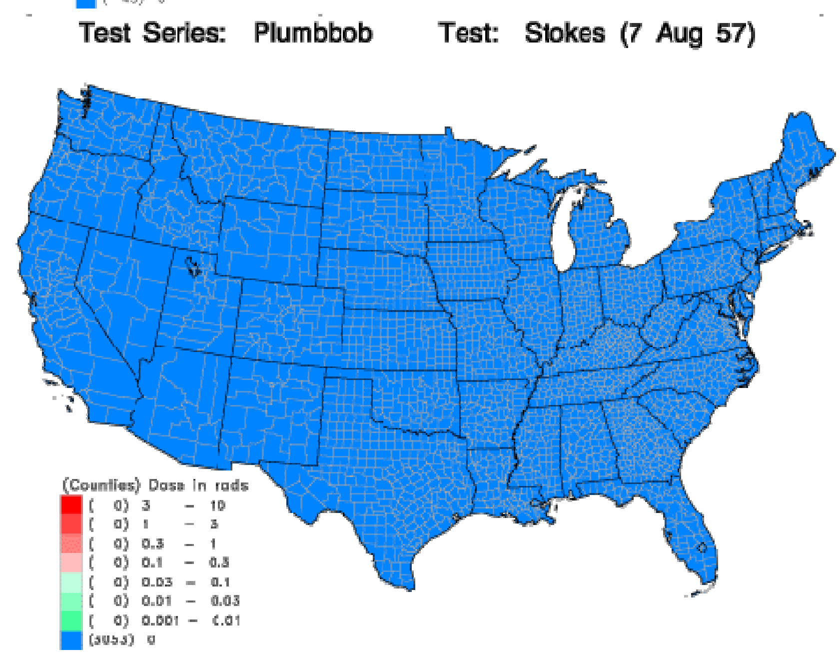


Hood & Stokes

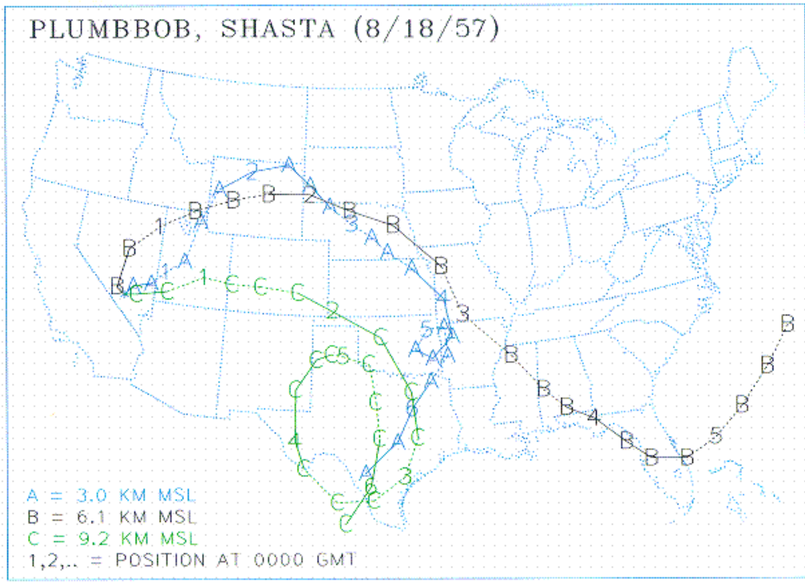

PLUMBBOB, HOOD (7/05/57)
A = 3.0 KM MSL
B = 6.1 KM MSL
C = 9.2 KM MSL
D = 11.8 KM MSL
E = 13.6 KM MSL
1,2,.. = POSITION AT 0000 GMT
- A.PB/4.16 -


Test Series: Plumbbob Test: Hood (5 Jul 57)
(Counties) Dose in rads
(0) 3 – 10
(0) 1 – 3
(107) 0.3 – 1
(449) 0.1 – 0.3
(1414) 0.03 – 0.1
(619) 0.01 – 0.03
(421) 0.001 – 0.01
(43) 0


PLUMBBOB, STOKES (8/07/57)
A = 3.0 KM MSL
B = 6.1 KM MSL
C = 9.2 KM MSL
D = 10.4 KM MSL
1,2,.. = POSITION AT 0000 GMT
- A.PB/7.12 -

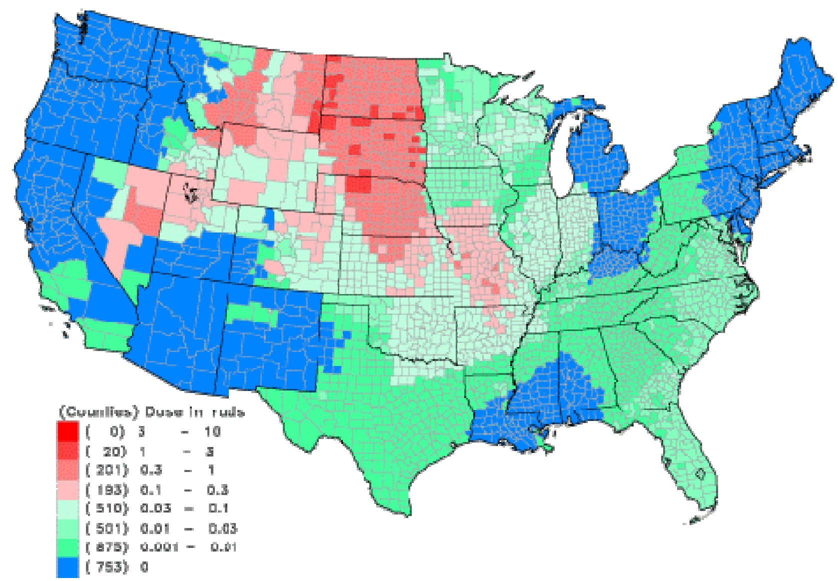

Test Series: Plumbbob Test: Stokes (7 Aug 57)
(Counties) Dose in rads
(0) 3 – 10
(0) 1 – 3
(0) 0.3 – 1
(0) 0.1 – 0.3
(0) 0.03 – 0.1
(0) 0.01 – 0.03
(0) 0.001 – 0.01
(3053) 0

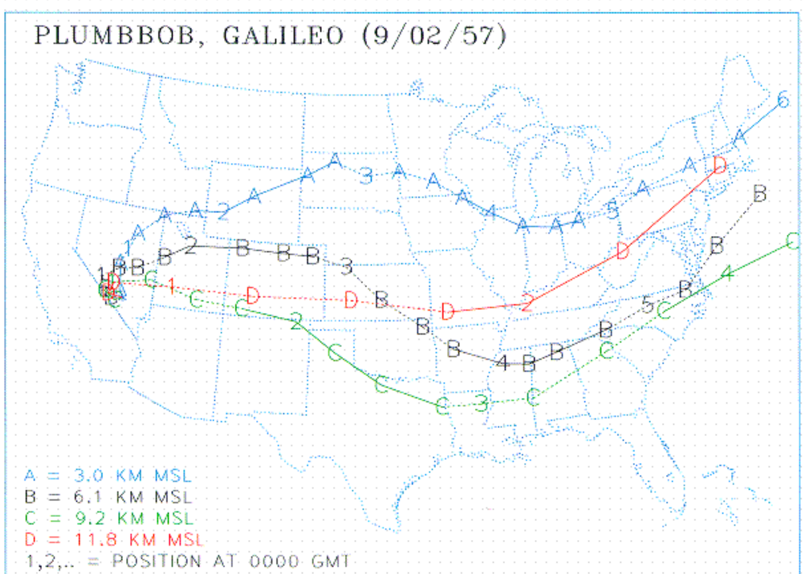
Shasta & Galileo



- A.PB/8.16 -

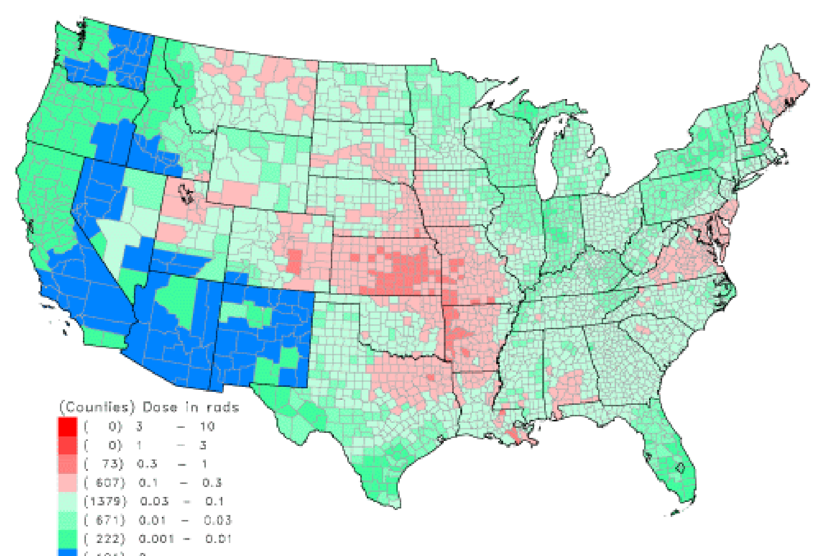
Test Series: Plumbbob Test: Shasta (8 Aug 57)





- A.PB/12.17 -

Test Series: Plumbbob Test: Galileo (2 Sep 57)



St. Josephs County, Indiana

Test Series	Average doses (rad) resulting from		Collective doses (man.rad)	
	milk consumption	all exposure routes	milk cons.	all exposure routes
	GM (rad)	GM (rad)	GM (rad)	GM (rad)
Ranger 1951	0.000	0.000	40.	76.
Buster Jungle 1951	0.000	0.001	81.	218.
Tumbler Snapper 1952	0.948	1.155	207935.	253403.
Upshot Knothole 1953	0.470	0.567	103099.	124325.
Teapot 1955	0.088	0.118	19301.	25883.
Plumbbob 1957	0.573	0.707	125717.	155118.
Underground 1961-1970	0.099	0.131	21680.	28834.

Fallout Radioactivity

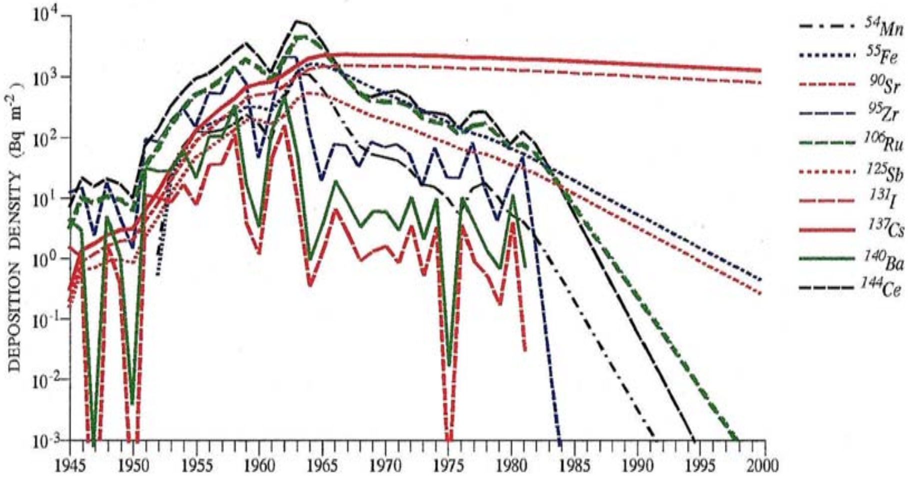


Figure VIII. Worldwide population-weighted cumulative deposition density of radionuclides produced in atmospheric testing. *The monthly calculated results have been averaged over each year. Several short-lived radionuclides with half-lives and deposition patterns intermediate between ^{140}Ba and ^{95}Zr are not shown.*

^{90}Sr ($T_{1/2}$=28y) is stored in human bone material because of its close Chemical resemblance to calcium.

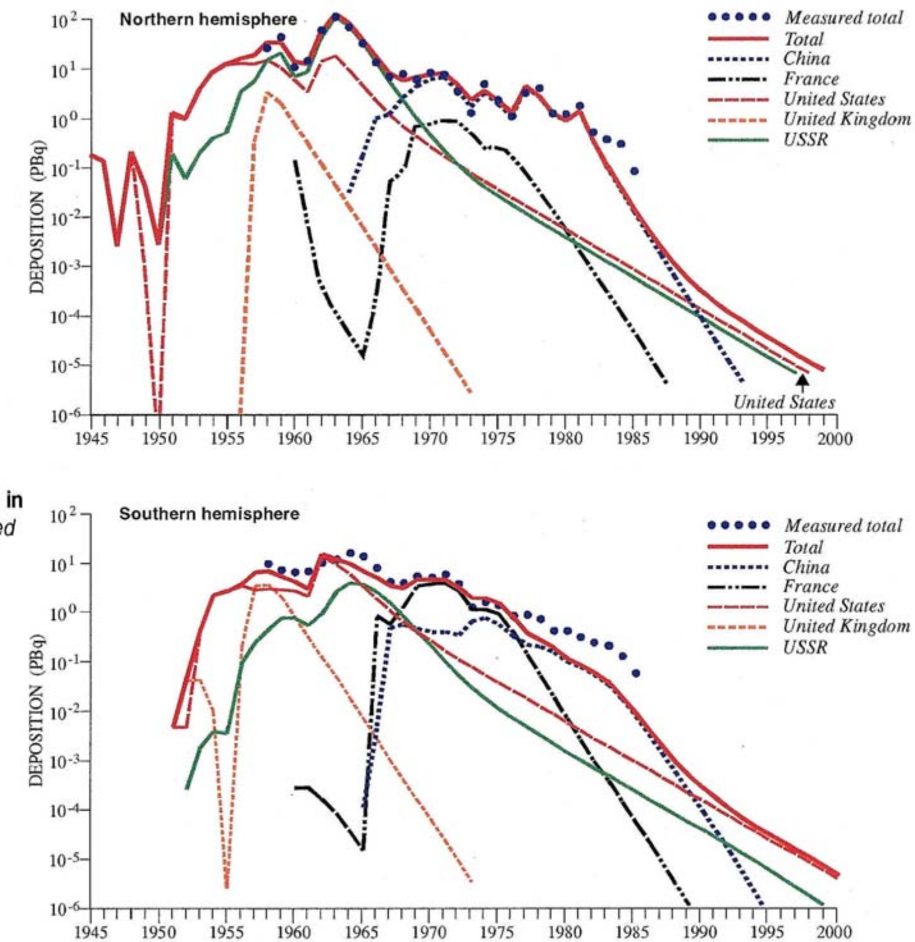
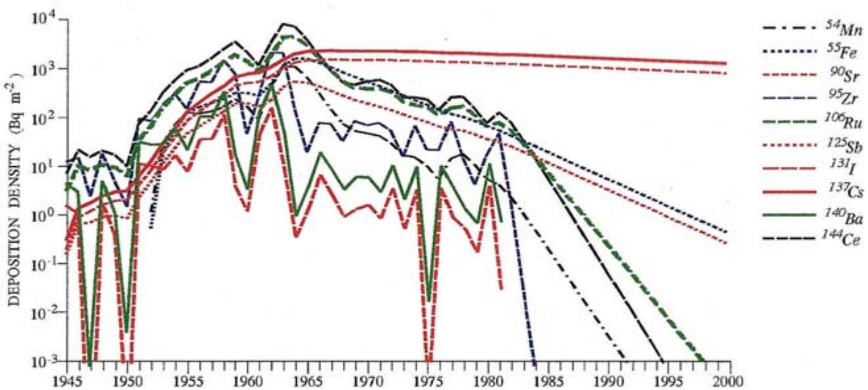
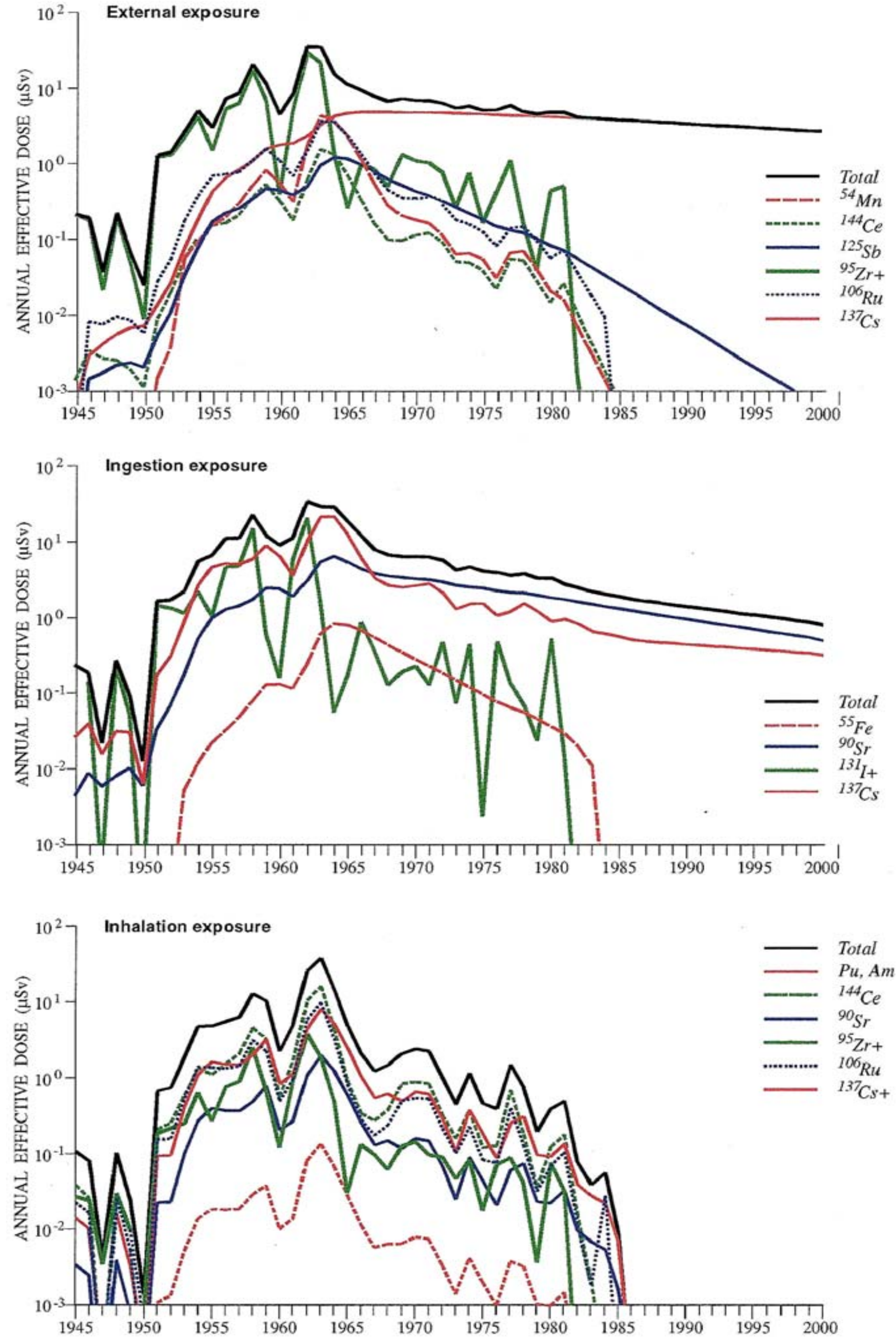


Figure VI. Components of strontium-90 deposition from test programmes of countries calculated from fission yields of tests with the atmospheric model.

Human Exposure from Nuclear Tests



Worldwide population-weighted cumulative deposition density of radionuclides produced in atmospheric testing. *The monthly calculated results have been averaged over each year. Several short-lived radionuclides with half-lives and deposition patterns intermediate between ^{140}Ba and ^{95}Zr are not shown.*



Worldwide average doses from radionuclides produced in atmospheric testing

External exposure: ^{95}Zr, ^{106}Ru, ^{140}Ba, ^{144}Cs

Ingestion exposure: ^{90}Sr, ^{131}I, ^{140}Ba

Inhalation exposure: ^{54}Mn, ^{55}Fe, ^{95}Sr, ^{125}Sb, ^{137}Cs

www.unscear.org/pdffiles/annexc.pdf

Expectations

- Grand Scale Nuclear Attack (war with other nuclear power)

  probability has declined with the demise of the Soviet Union – China has not emerged as a comparable nuclear power but its arsenal is growing

- Small Scale Nuclear Attack (terrorist incident)

  large scale attack with full nuclear warhead depends on availability of fissionable material. Most likely source former Central Asian Soviet Republics which had maintained a considerable stockpile. “Dirty bombs” are inconsequential, paranoia driven idea in media and politics.

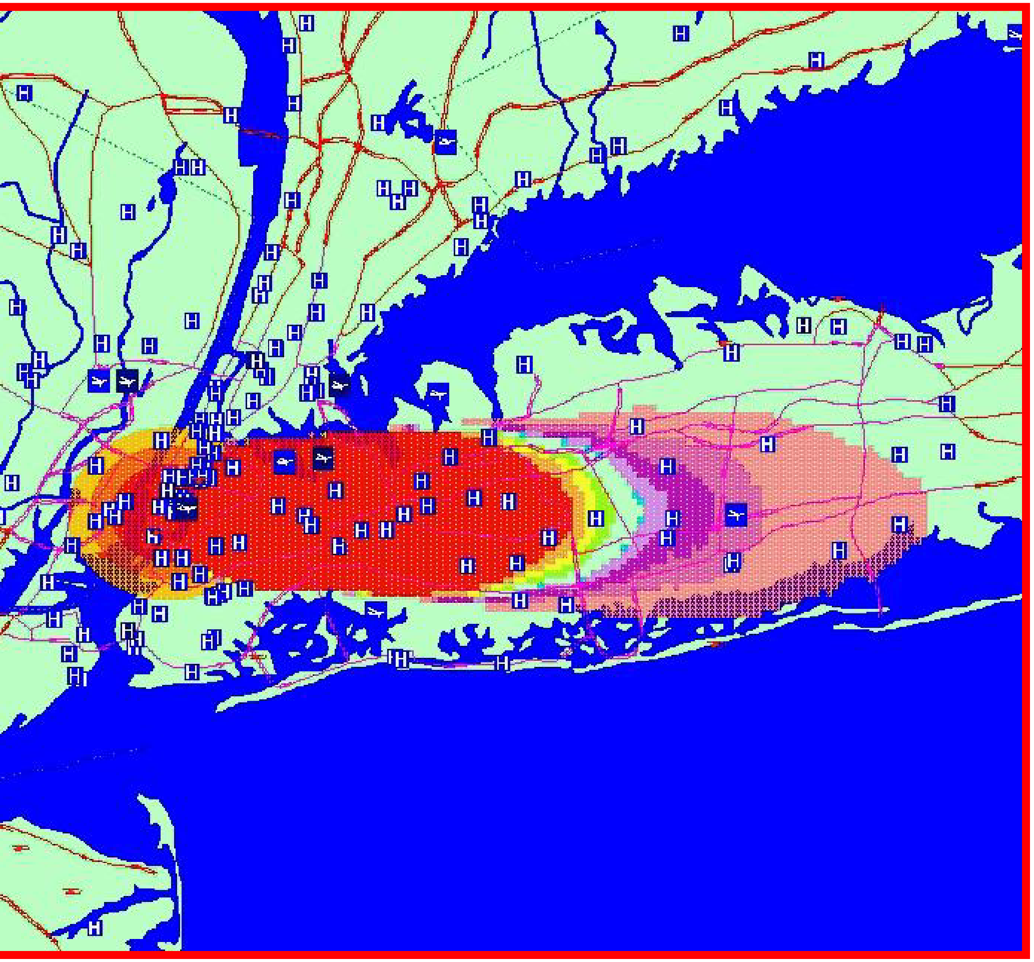
- Global Consequences of Nuclear War (nuclear winter)

  only possible in case of global nuclear conflict

Grand Scale Nuclear Wars

Would include attacks on all major US cities With disastrous consequences for population Immediate high death toll and extreme high rate on heat and radiation induced injuries and health problems. This, coupled with insufficient medical support system will lead to complete collapse of civilian structures. Presently low probability to take place.

New York City – 250 kT Nuclear Bomb



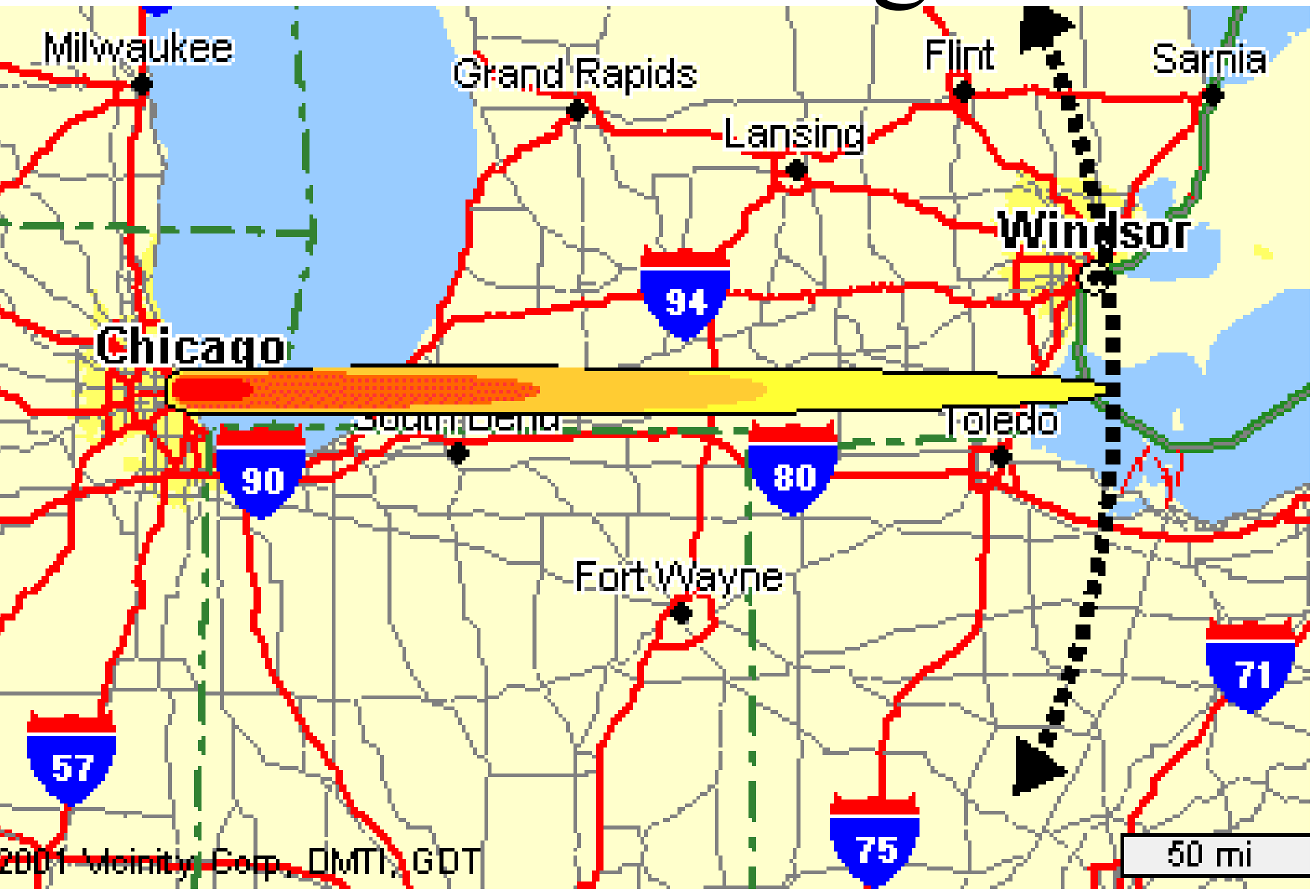
warhead of that size is only available in major arsenals The likelihood of a major nuclear attack on New York of that scale is small.

Mortality Probability

3.9 million people would be affected

Red	90%	Dark Blue	40%
Lt Brown	80%	Lt Purple	30%
Yellow	70%	Dk Purple	20%
Green	60%	Dk Pink	10%
Pale Blue	50%	Lt Pink	1%

Attack on Chicago



90 Rem*
Distance: 250 miles
No immediate harmful effects, but decrease in white blood cells.
2 – 3 years before considered 'safe'.

3,000 Rem*
Distance: 30 miles
Lethal dose within hours
10 years before area is safe

900 Rem*
Distance: 90 miles
Lethal dose:
2 – 14 days

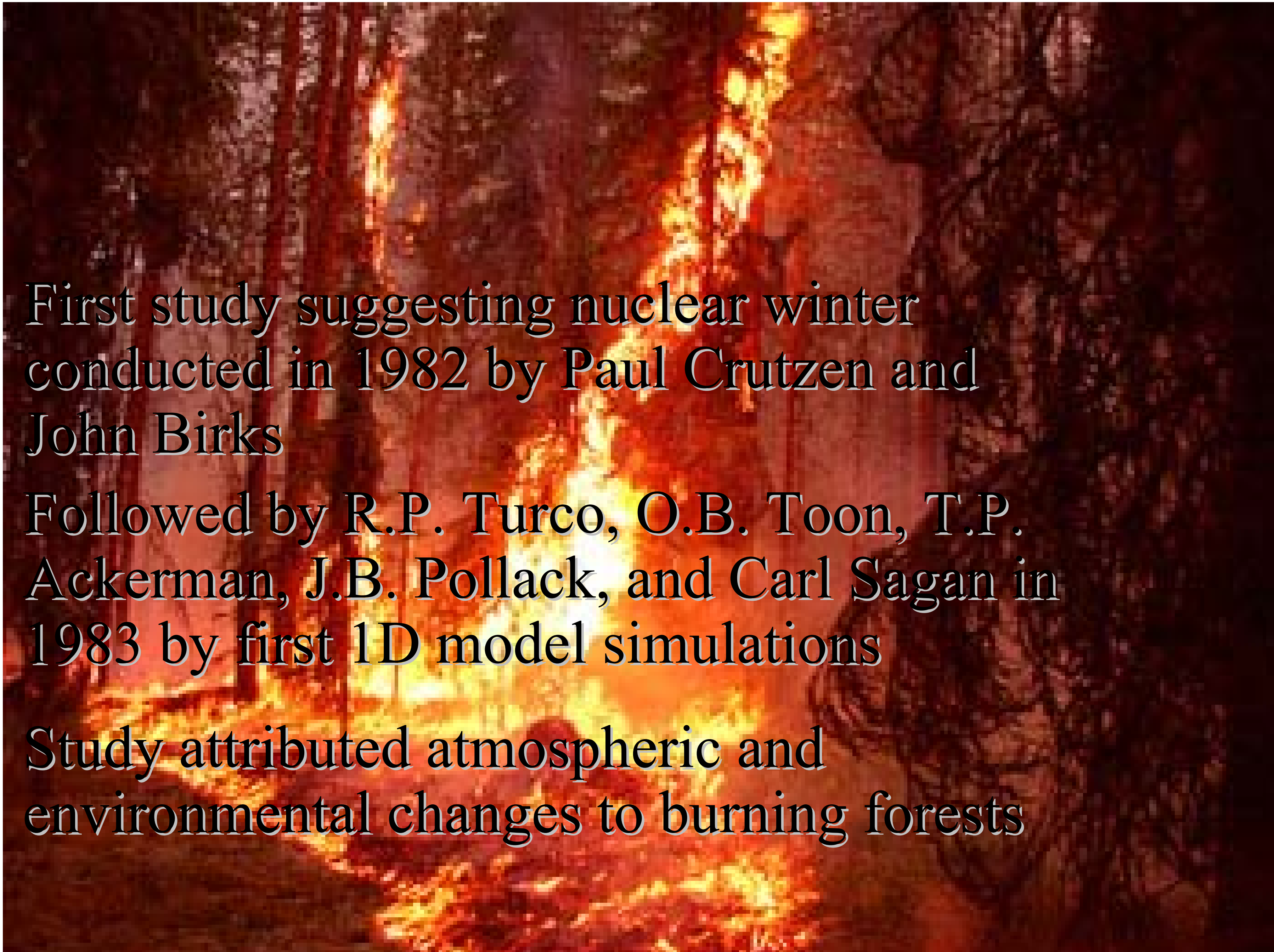
300 Rem*
Distance: 160 miles
Extensive internal damage

*Based on 15 mph winds

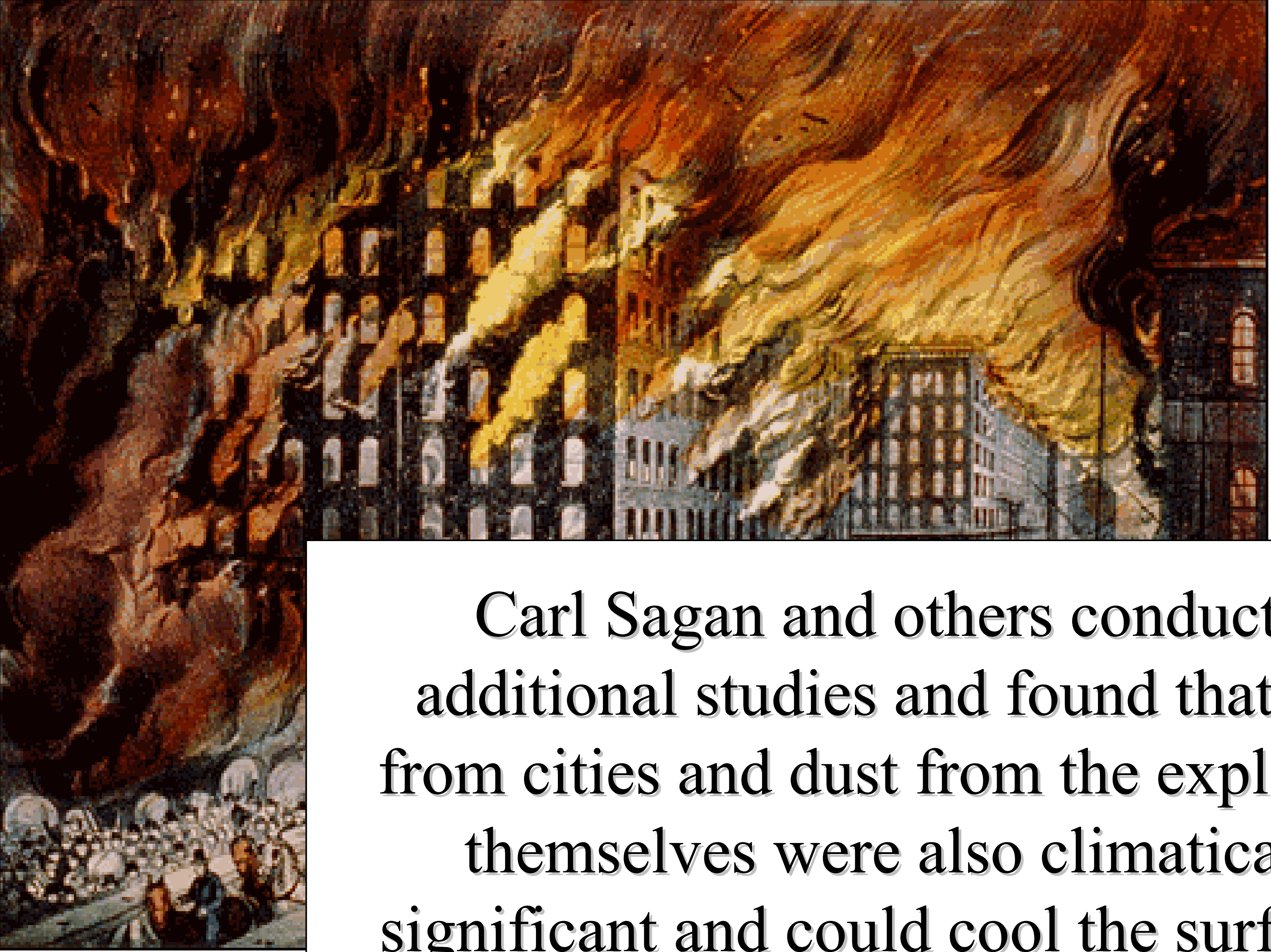
Nuclear Winter

What is Nuclear Winter?

Prediction by some scientists that smoke and debris rising from massive fires of a nuclear war could block sunlight for weeks or months, cooling the earth's surface and producing climate changes that could, for example, negatively affect world agricultural and weather patterns. (EPA)



- First study suggesting nuclear winter conducted in 1982 by Paul Crutzen and John Birks
- Followed by R.P. Turco, O.B. Toon, T.P. Ackerman, J.B. Pollack, and Carl Sagan in 1983 by first 1D model simulations
- Study attributed atmospheric and environmental changes to burning forests



Carl Sagan and others conducted additional studies and found that soot from cities and dust from the explosions themselves were also climatically significant and could cool the surface of the earth

In 1983, R.P. Turco, O.B. Toon, T.P. Ackerman, J.B. Pollack, and Carl Sagan (referred to as TTAPS) published a paper entitled "*Global Atmospheric Consequences of Nuclear War*" which is the foundation that the nuclear winter theory is based on.

The theory states that nuclear explosions will set off firestorms in the cities and surrounding forest areas. The small particles of soot are carried high into the atmosphere. The smoke will block the sun's light for weeks or months. The land temperatures would fall below freezing.

This combination of reduced temperatures and reduced light levels would have catastrophic ecological consequences. Average light levels would be below the minimum required for photosynthesis during the first 30-40 days after the explosion and most fresh water would be frozen. The TTAPS study concluded: "...the possibility of the extinction of Homo Sapiens cannot be excluded." This effect is similar to what may have killed the dinosaurs.

Consequences of Climatic Changes

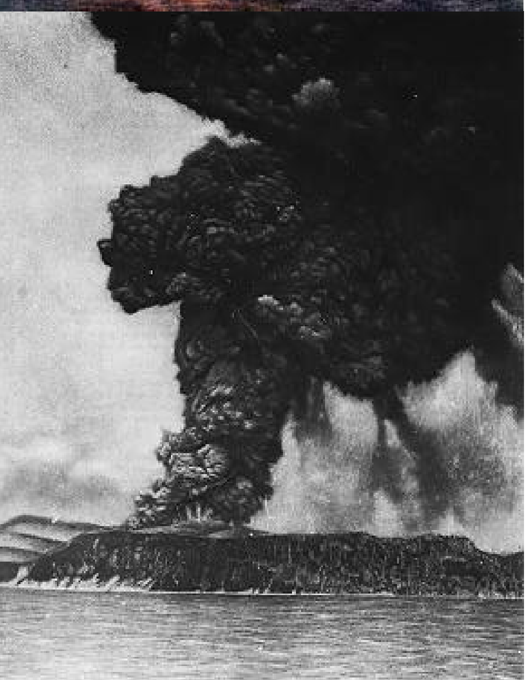
Natural Disasters

Nuclear winter theory is supported by observational evidence from natural catastrophic events:

- ❑ Volcano eruptions

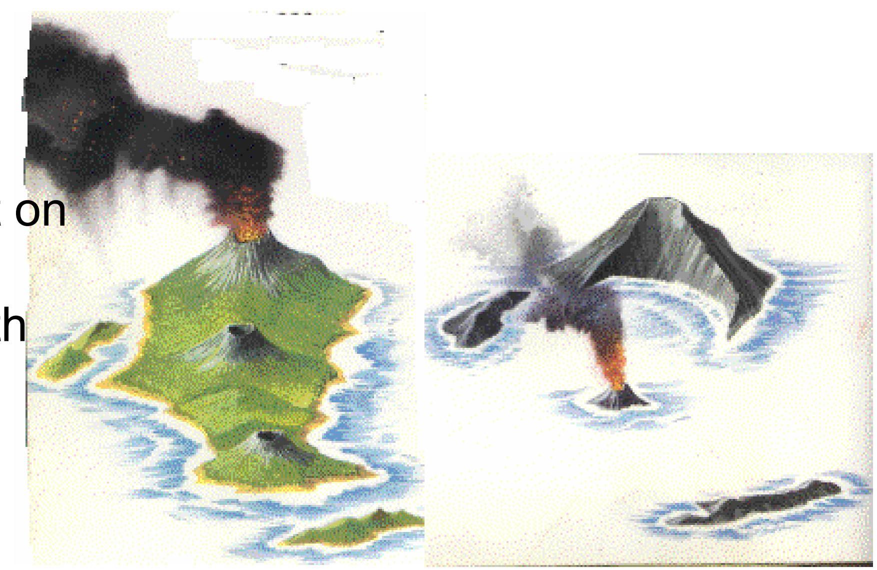
- ❑ Asteroid impact

- ❑ Bushfires



>130 active volcanoes in Indonesia,
Krakatau eruptions: 535 AD, 1883 AD, 200X

Considerable impact on global temperatures was recorded for both volcano events!



Krakatau

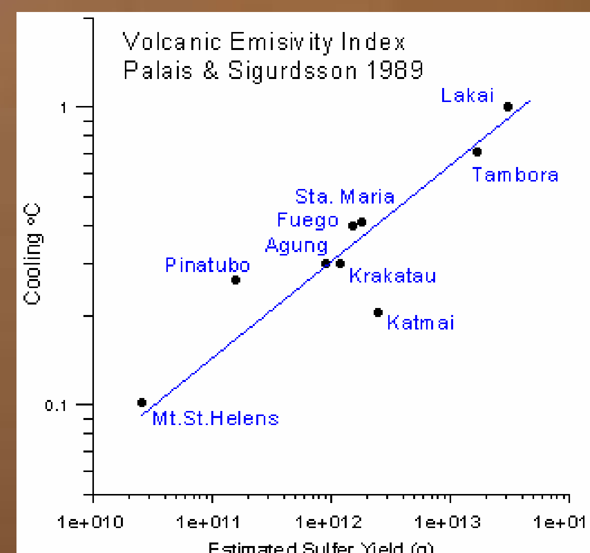
Krakatau eruption 535-536 AD According to ancient records “Pustaka Raya Purwa” splitting Sumatra and Java!

“There was a sign from the sun, the likes of which have never be seen or reported before. The sun became dark and the darkness lasted for 18 months. Each day it shown for about 4 hours and still this light was only a feeble shadow.”

John of Ephesus,
Bishop of Syria

Significant drop in temperature due to sun light absorption in emitted dust and aerosols!

Sulfuric acid emission; evidence in Greenland and Antarctic ice cores



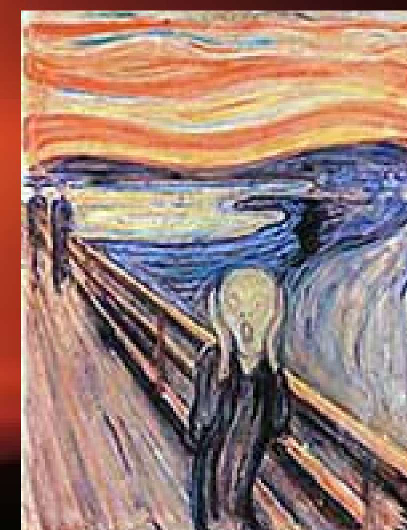
Santorini: 1627 BC, 5° cooling!

Effects on Sunset

Scattering effects of photons on sub-micron sized particles in the dusty stratosphere & troposphere

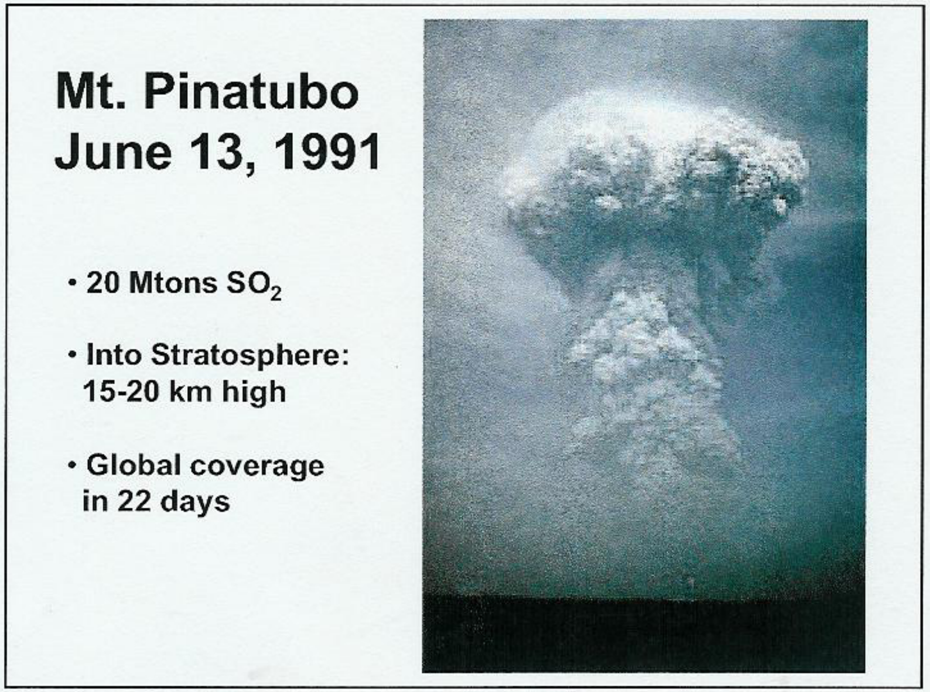
Spectacular sunrise and sunset colors from sulfuric particles and dust:
Painting by William Ashcroft November 1883

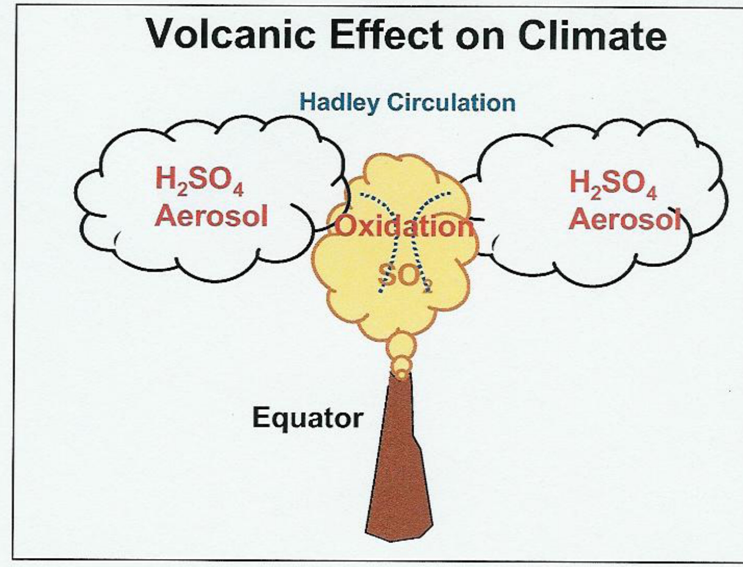
Krakatau's impact on art!

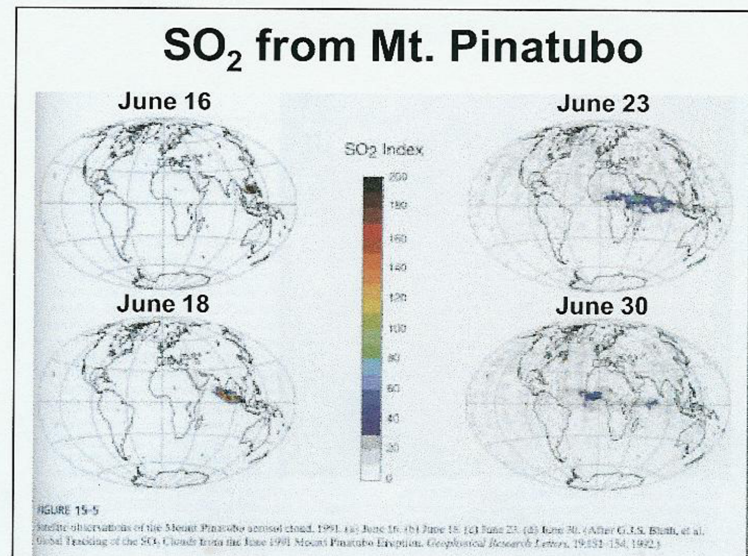


The vivid red sky in Edvard Munch's painting "The Scream" was inspired by the twilights in Norway

Sulfur and Aerosol Effects





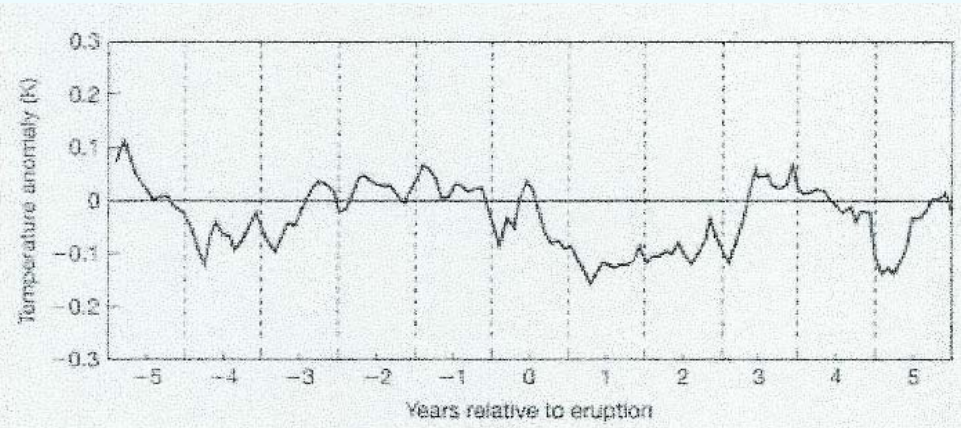


$$SO_2 + OH + 3H_2O \Rightarrow H_2SO_4 + 2H_2O$$

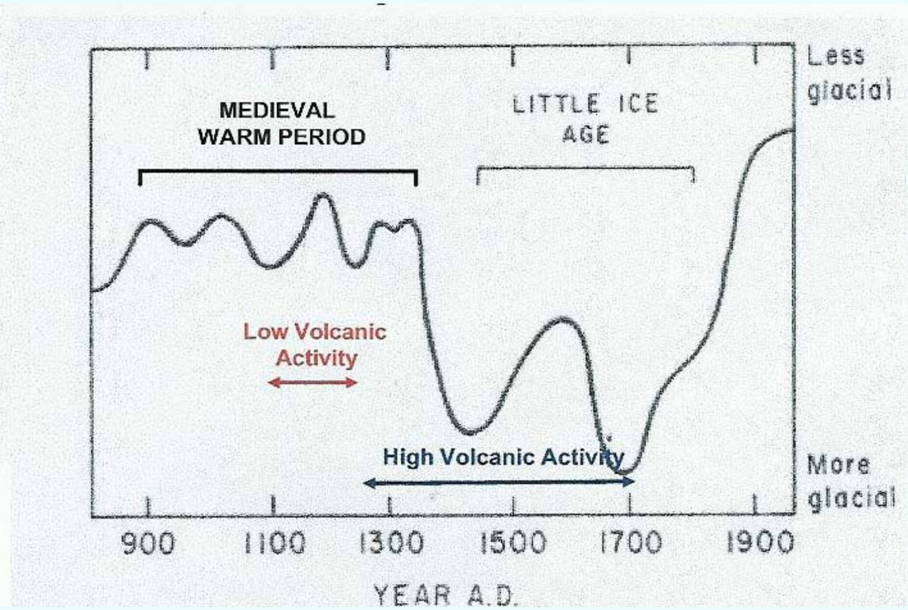
Conversion of ejected gaseous SO_2 into H_2SO_4 within six months

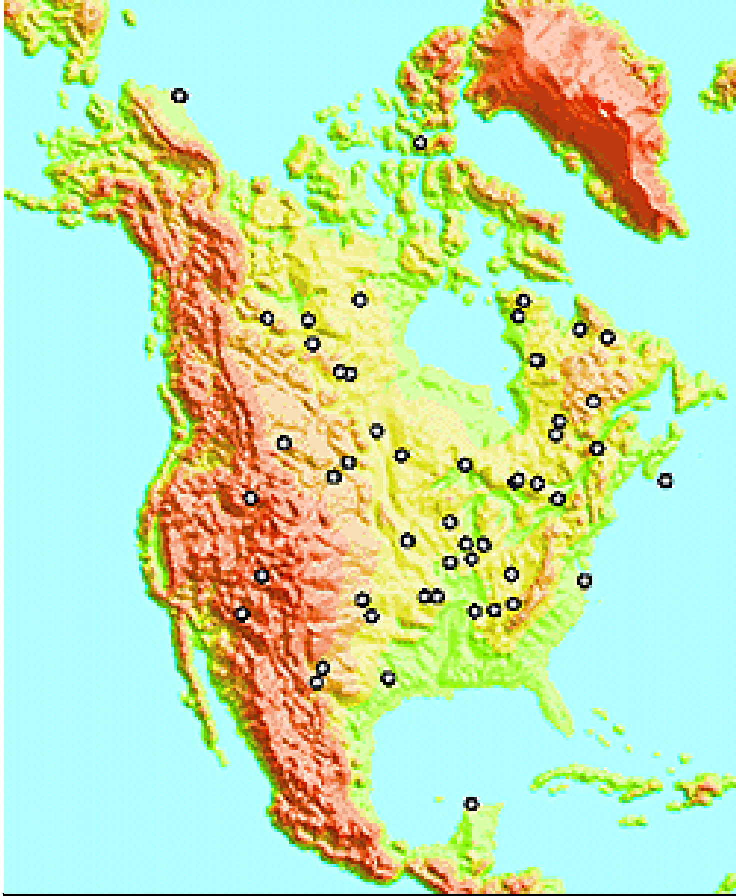
Increase of stratosphere temperature by ~4°, decrease of temperature in hemisphere by ~0.2°.

Effects on global temperature



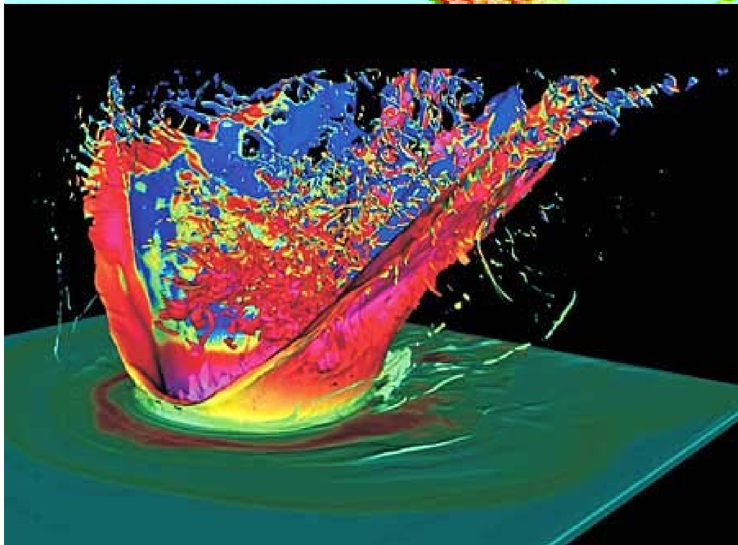
Average Impact of Krakatau (1883), Santa Maria (1902), Katmai(1919), Agung (1963),El Cichon(1982), on temperatures recorded by the GISP2 ice core.





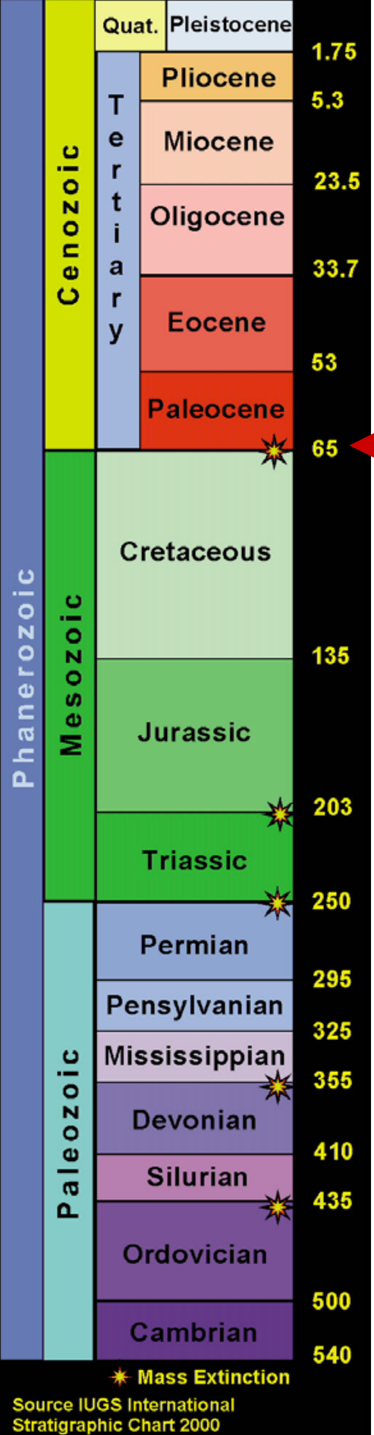
Asteroids

Relatively frequent events over the age of the earth, 47 are recorded on North American continent



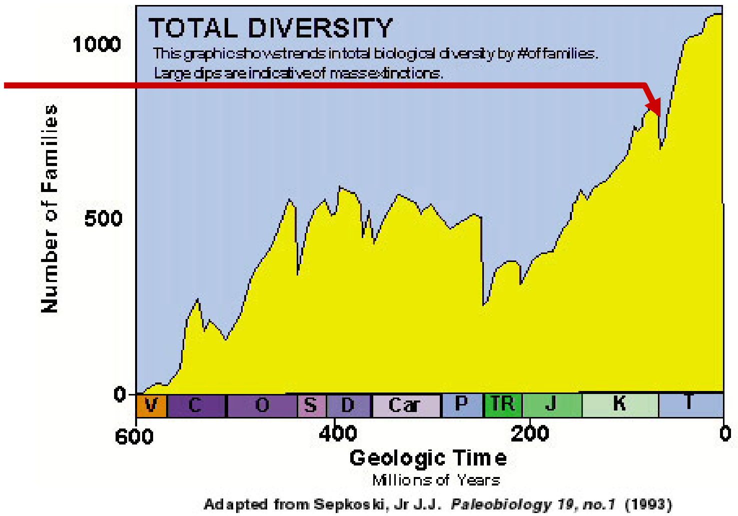
Artist's conception & computer simulation

same conclusion:
⇒ **BIG SPLASH!**



Geological Time-scales

Catastrophic events are often associated with drastic geological changes. The best known example is correlated with the end of the Cretaceous period. This change is correlated with the sudden extinction of the Dinosaurs as well as with the disappearance of 60-80% of the existing marine species.



FREQUENCY OF IMPACTORS:

Pea-size meteoroids - 10 per hour
Walnut-size - 1 per hour
Grapefruit-size - 1 every 10 hours
Basketball-size - 1 per month
50-m rock that would destroy an area the size of New Jersey - 1 per 100 years
1-km asteroid - 1 per 100,000 years
2-km asteroid - 1 per 500,000 years
A "nemesis" parabolic comet impactor would give us only a 6-month warning.

Common explanation, impact of a large asteroid which caused dust eruption and long term decrease of global temperatures.

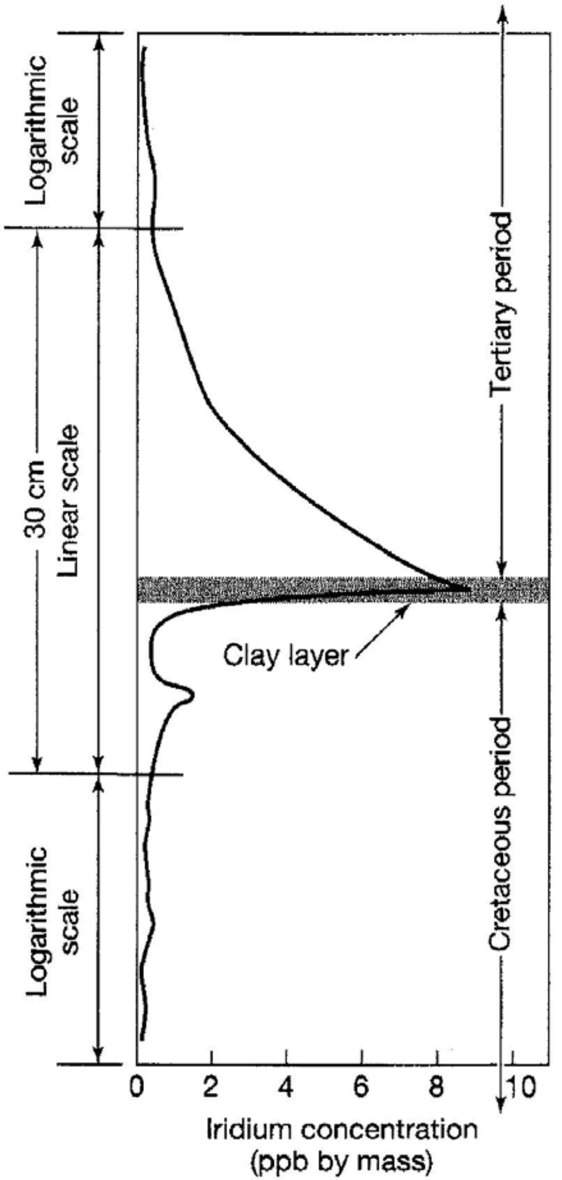
Evidence for the Impact Hypothesis?

Walter Alvarez (and his father Louis, who won the Nobel Prize for discovering Tritium), found high levels of iridium in a clay layer at the Cretaceous-Tertiary (K-T) boundary. High levels of Iridium are only found in extraterrestrial material. Since then, similar layers have been found elsewhere. A large crater of the right age has been located in the Yucatan Peninsula.

Artist: Don Davis (the scale is wrong!)

http://geowww.gcn.ou.edu/~jahern/impacts/chicxulub.html

Iridium rich layer



Impact energy

The impact energy deposited = the *kinetic energy* (*KE*) of incoming object, where

$$KE = \frac{1}{2} M \cdot v^2$$

ν is large! Orbital velocity ~ 30 km/sec = 66,000 mph

Mass is large! $$M = \rho \cdot V = \rho \cdot \frac{\pi \cdot d^3}{6}$$ where d is the diameter of the object.

For rocks, Density ~ 5 gr/cc ===> Mass ~ 2.5 d^3 tons, with d in meters

Converting to equivalent explosive energy in units of tons of TNT. 1 ton TNT = 4 x 10^{16} ergs.

===> Impact energy = 250 d^3 equivalent tons of TNT.

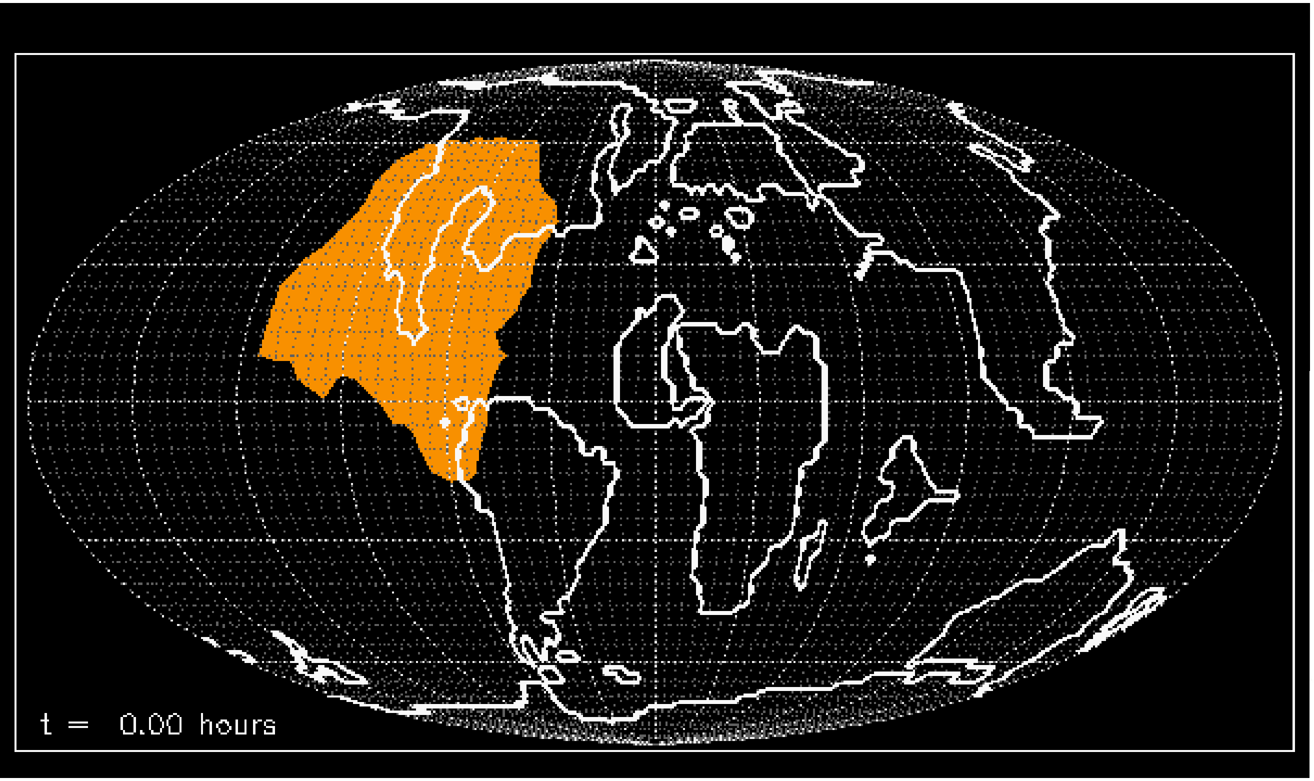
An object with d=4 meters packs the explosive power of the Hiroshima bomb (20,000 tons).
If d=200 meters, a common size of asteroid, energy = *2 billion tons of TNT=2000 Megatons!*

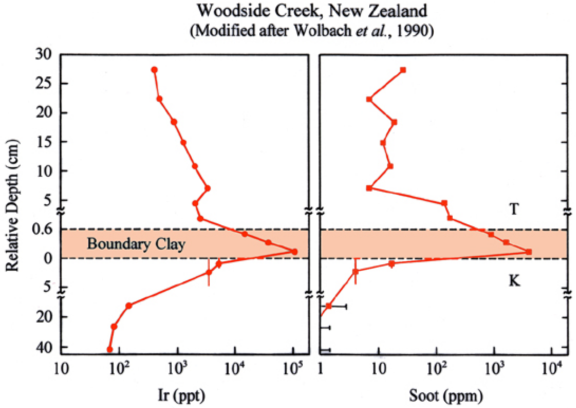
City Buster: 15-m meteoroid ===> $8.5 \cdot 10^5$ tons TNT ≈ 1 Megaton (MT). Serious local consequences, though atmosphere provides partial shield. Hydrogen-bomb scale, but without the radioactivity.

People Buster: 1-km asteroid ===> 250,000 MT. No atmospheric shield. Hemispheric-scale effects. At threshold for global effects. Significant fraction of all humans killed.

Planet Buster: 10-km diam asteroid ===> 250 million MT. *global* effects. Ejected, vaporized rock and water fill atmosphere ===> *global winter* ===> major extinction of life forms, including virtually all humans.

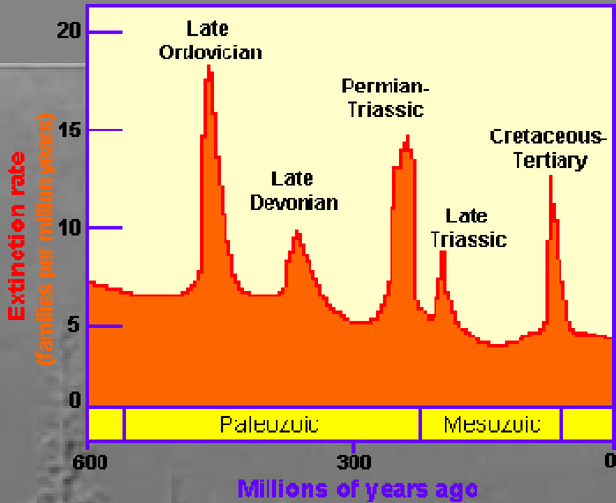
Further consequences of smaller asteroid impact: Spreading of wild fires





Observational evidence in soot layers associated with Iridium enrichment

Dire Consequences

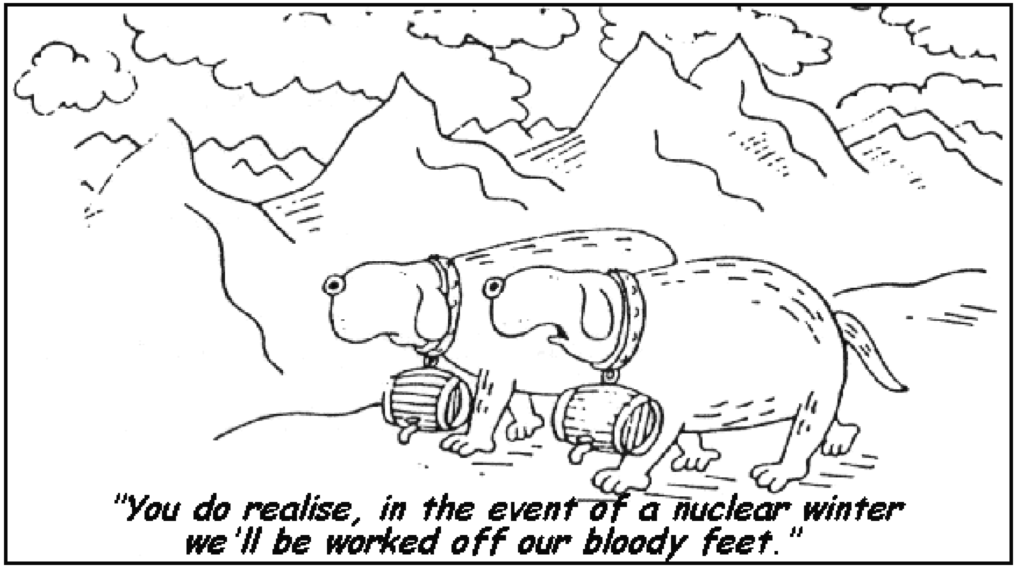


The Chicxulup event corresponds to 70 Million Megaton TNT
~ 7000 times the maximum arsenal of US and Soviet Union!

Scientific Studies on Nuclear Winter

- U.S. National Academy of Sciences
  http://books.nap.edu/openbook/0309036925/html/136.html
- The Royal Society of Canada
  http://www.nap.edu/books/0309036925/html/553.html
- U.S. Department of Defense
- USSR

All studies conclude
"a clear possibility"
of serious climatic
consequences



Causes of Change

- Forest Fires
- Pyrotoxins
- Dust from blasts
- Soot from cities burning
- Widespread ionizing radiation

Reduction of sun light follows absorption law:

$$I = I_0 \cdot e^{-\tau}$$

τ is absorption coefficient which depends sensitively on dust size and content, dust, aerosols, etc!

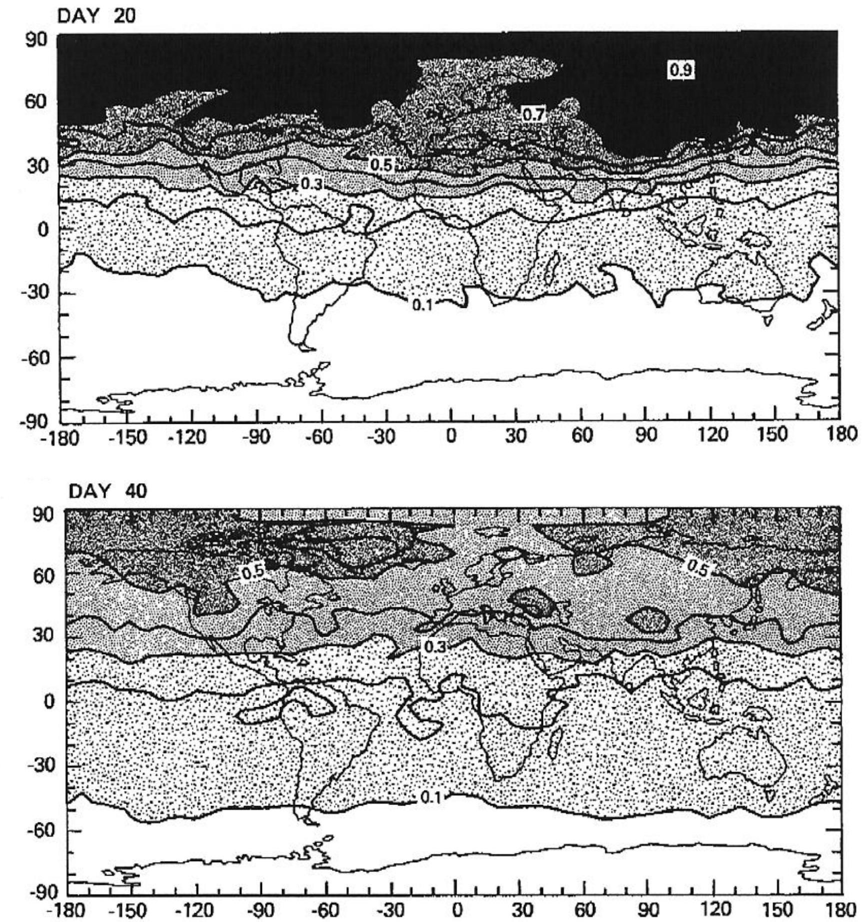
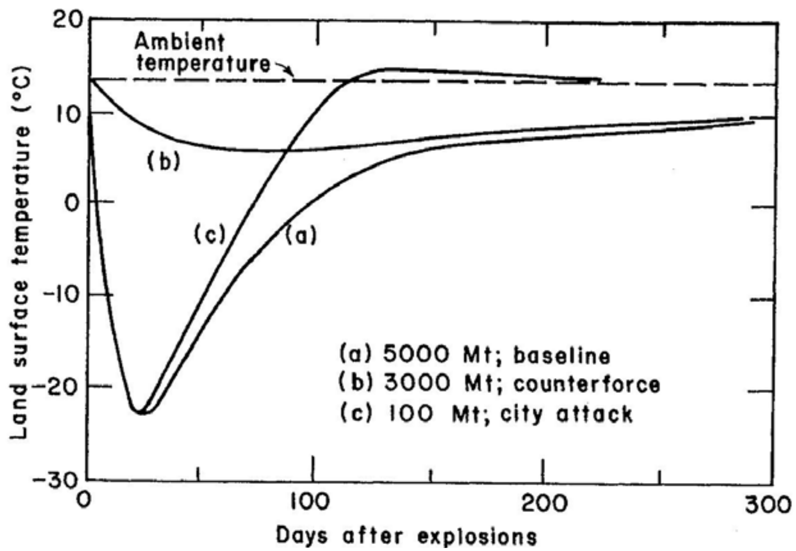


FIGURE 6 The vertically integrated solar absorption optical depth of smoke at day 20 (A) and day 40 (B) of the interactive July simulation with 170 Tg injected with the NAS vertical profile. The contours are presented at intervals of 0.1, with the lowest value being 0.1 on the southernmost contour. If τ is the absorption optical depth, the light reaching the surface from the sun overhead is reduced by a factor of $e^{-\tau}$. For τ = 0.1, 0.3, 0.5, and 0.7, the factor $e^{-\tau}$ is 0.90, 0.74, 0.61, and 0.50, respectively. Source: Malone et al. (1986, p. 1047).

Impact on temperatures



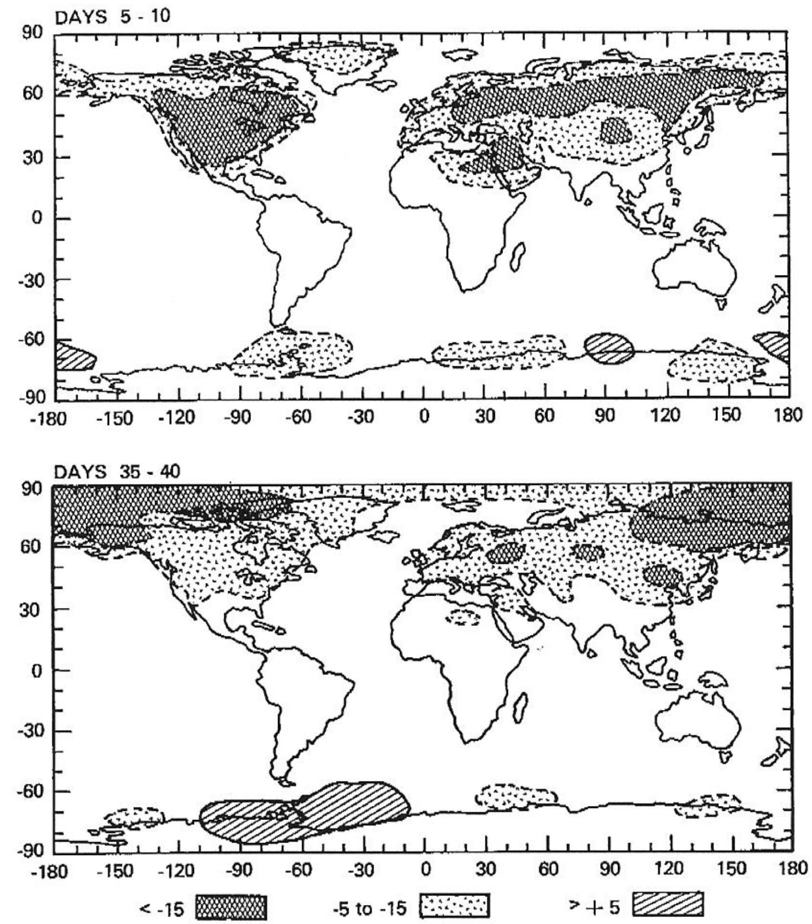


FIGURE 7 The change in surface air temperature relative to the unperturbed atmosphere in July for 170 Tg of smoke injected with the NAS profile. Five-day averages of the perturbed case, minus the long-term average of the unperturbed case, are shown: (A) days 5–10, (B) days 35–40. Only changes larger in magnitude than 5°C are shown. Values are indicated at the bottom of the figure; the designation <-15 refers to temperature reductions below normal in excess of 15°C. Note that the warm and cool regions near Antarctica are simply manifestations of storms which occur naturally in the wintertime circumpolar flow; they have no connection with the changes occurring in the Northern Hemisphere.

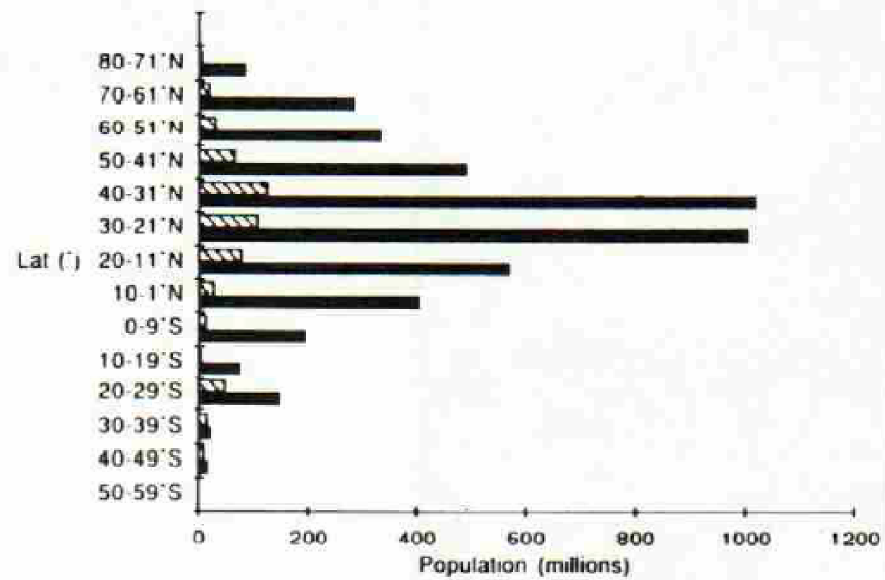
TTAPS study assumed 5000 Mt first strike with 0.1-0.33 Mt of dust per 1Mt of TNT exploded. The model estimates 225 Mt smoke emission and 960 Mt dust emission (≈ 960 Tg). The optical absorption parameter was calculated to:

$\tau \approx 4.5$ indicating ~99% absorption!
Drop in temperature by up to 40^{o}C!

Impact for food supply

- Foodstuffs are vulnerable to even a 5-10 degree average change, depending on selectivity
- The "Little Ice Age" of the 16th – 17th centuries was only an average of one degree less than mean temperatures.

FIGURE 1. Estimated deaths from starvation following a nuclear war that occurs when foodstocks are low.



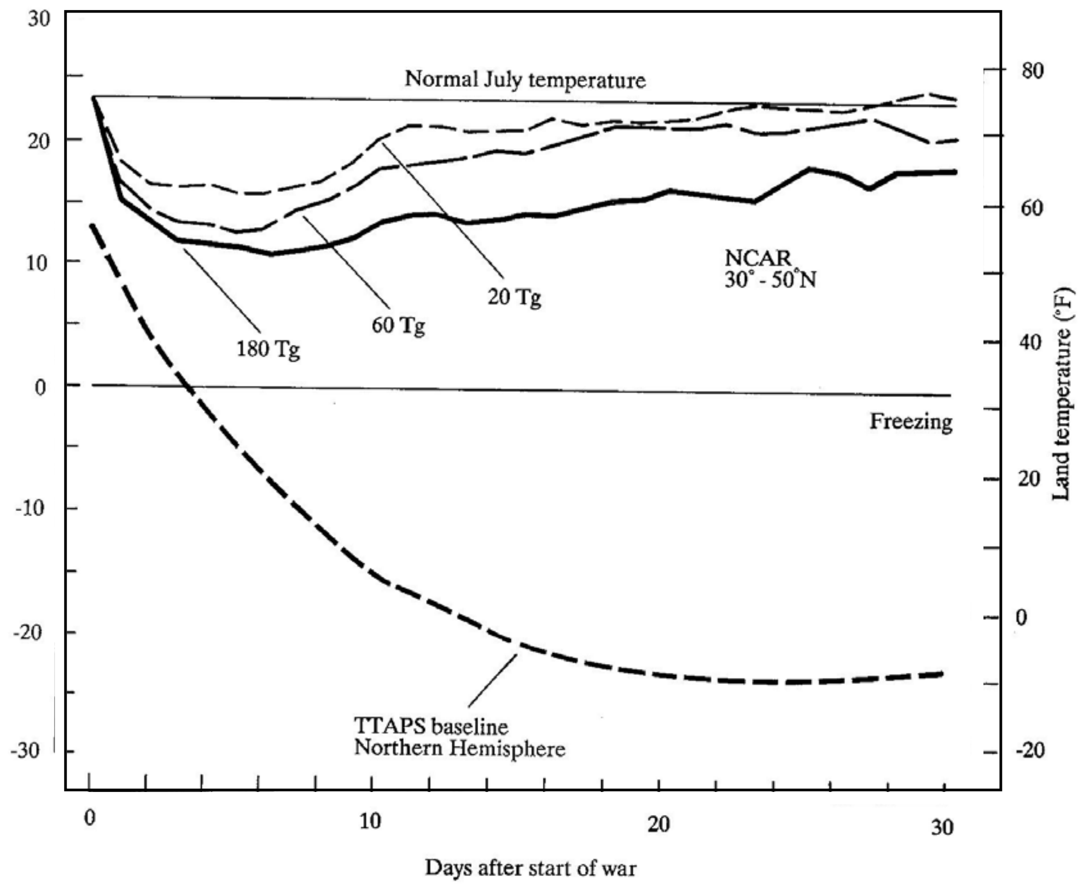
Solid bars show present populations in each latitude band. Striped bars show surviving populations in same latitudes after a major nuclear war. The prompt fatalities—variously estimated to be between a few hundred million and 2.2 billion people—are not shown.

SOURCE: SCOPE, *Environmental Consequences of Nuclear War*, SCOPE 28 (Chichester and New York: John Wiley & Sons, 1985), II, 480.

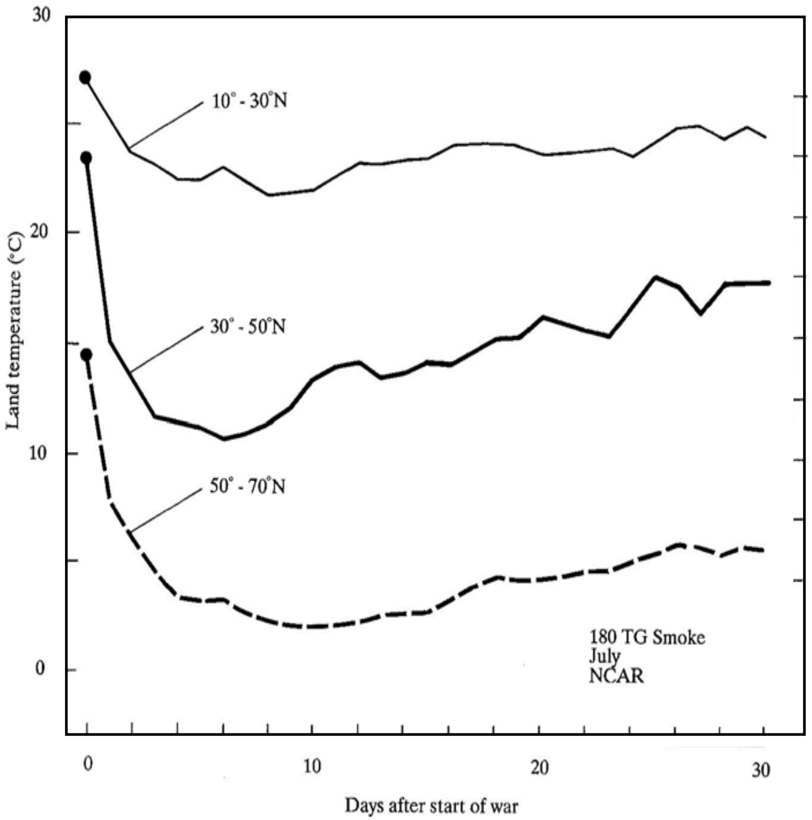
Revised Studies

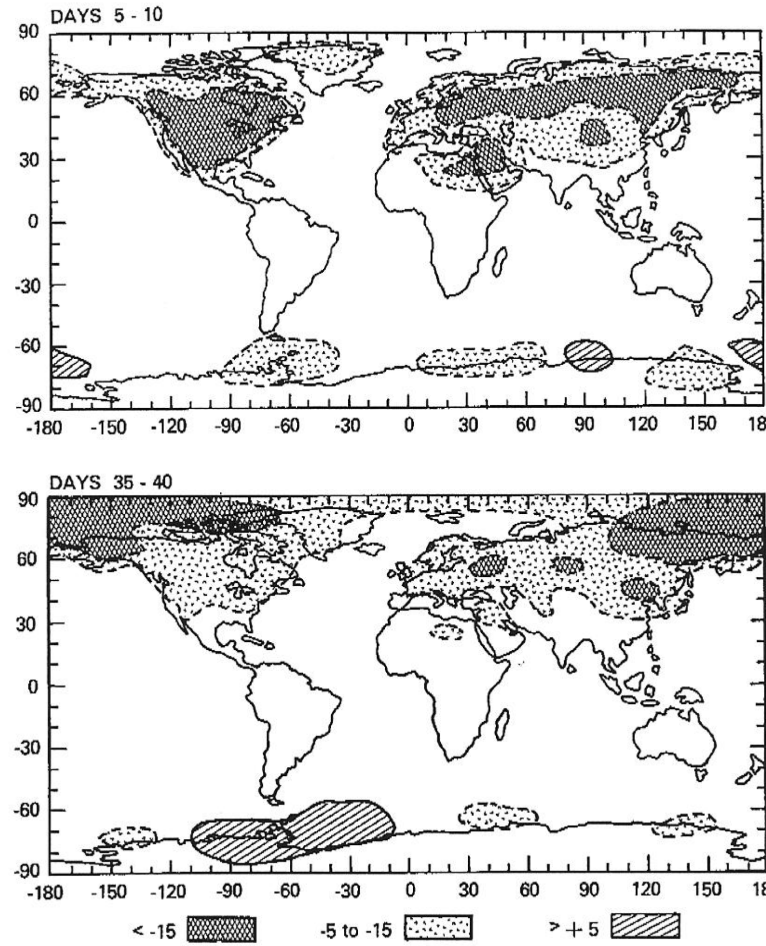
3D model simulations (Malone et al. 1986) taking into account more complex atmospheric parameters reduce the absorption coefficient predictions. Takes also into account removal of dust by wind and rainfall. Significant lower dust emission of < 200 Mt!

Average summer temperature at Northern hemisphere drops by 10 ^oF



Latitude effects





3-6 month cooling period, depending on weather and rainfall conditions. Only limited spread to Southern hemisphere except for wind related changes in Antarctic regions

The New Fear: Terrorists!

Since 911 fear of terror attacks dominates the discussion. The fear of nuclear terror through small or medium sized "nuclear bombs" from former Soviet arsenals and fear of "dirty bombs" makes headline news in the media channels.

Terror as a Weapon

Terrorism is the … deliberate targeting of Civilians in order to undermine their support for the politics of their political leaders" (Caleb Carr 2002)

Deliberate use by military forces

- o Roman Army: 1st to 3rd century
- o Mongol Armies: 13th to15th century

- o German Navy: unrestricted submarine warfare in WW1
- o German Army: occupation armies
- o Japanese Army: Manchuria, China, Philippines, …
- o Spanish Army: Civil War in Spain
- o British Air Force: Bomb War against cities in WW2
- o US Air Force: Bomb War against civilian targets Germany& Japan in WW2,
  Hiroshima & Nagasaki
  Vietnam
- o Israeli Army: Palestine population
- oYugoslav Army: Muslims, Croats, Albanians
- o Indonesian Army: East Timor

And many examples more ….

Guerilla

Guerilla: civilian fighters against occupying forces:

- o Spanish Guerilla (little war) against Napoleonic troops
- o Russian partisans against German Armies
- o French Resistance against German Armies
- o Kuomintang & Red Army against Japanese Occupation

Strictly against military occupation forces and collaborators

- o American Revolution against British Rule
- o Mau-Mau Uprising against British Colonial Rule in Kenya
- o Vietminh against French Colonial Forces in Vietnam
- o Front de Libération Nationale – FLN fighters against French Colonial Forces in Algeria
- o Vietcong against US occupation in South Vietnam
- o East Timor against Indonesian occupation

Against occupation and colonial forces including civilians (settlers, farmers)

Second category often depicted as terrorist acts against legal government institutions!

Terrorist Movements

Terrorist actions target mainly civilian population and structures avoiding military & government installations

- o Assassins in 9th-13th century middle east
- o Anarchist terror in 19th century Europe
- o Ku Klux Clan in the US
- o IRA in Ireland and Great Britain
- o Irgun Zvai Leumi & Lehi movement in Israel
- o Al Fatah in Israel, Jordan, Palestine
- o Red Army Fraction in Germany
- o Red Brigades in Italy
- o Euskadi Ta Askatsuna in Spain
- o Shining Path in Peru
- o Zapatista movement in Mexico/US
- o Oklahoma City bombing
- o Unibomber (Ted Kaczynski)
- o Right to life movements
- o Islamic Al Qaeda

Timothy McVeigh
Osama bin Laden

Delhi on nuke terror alert!

Al-Queda's Suitcase nuclear bomb made with stolen nuke equipments from Iraq and expertise from Pakistan!

Sudhir Chadda, Special Correspondent
October 12, 2004

Awareness in US population

Confusion in US about differences between guerilla & terrorist!
Ignorance and confusion also about geographical location, historic reason, historic, economic, and sociological background of terrorist attacks.

“Terrorists” Attacks

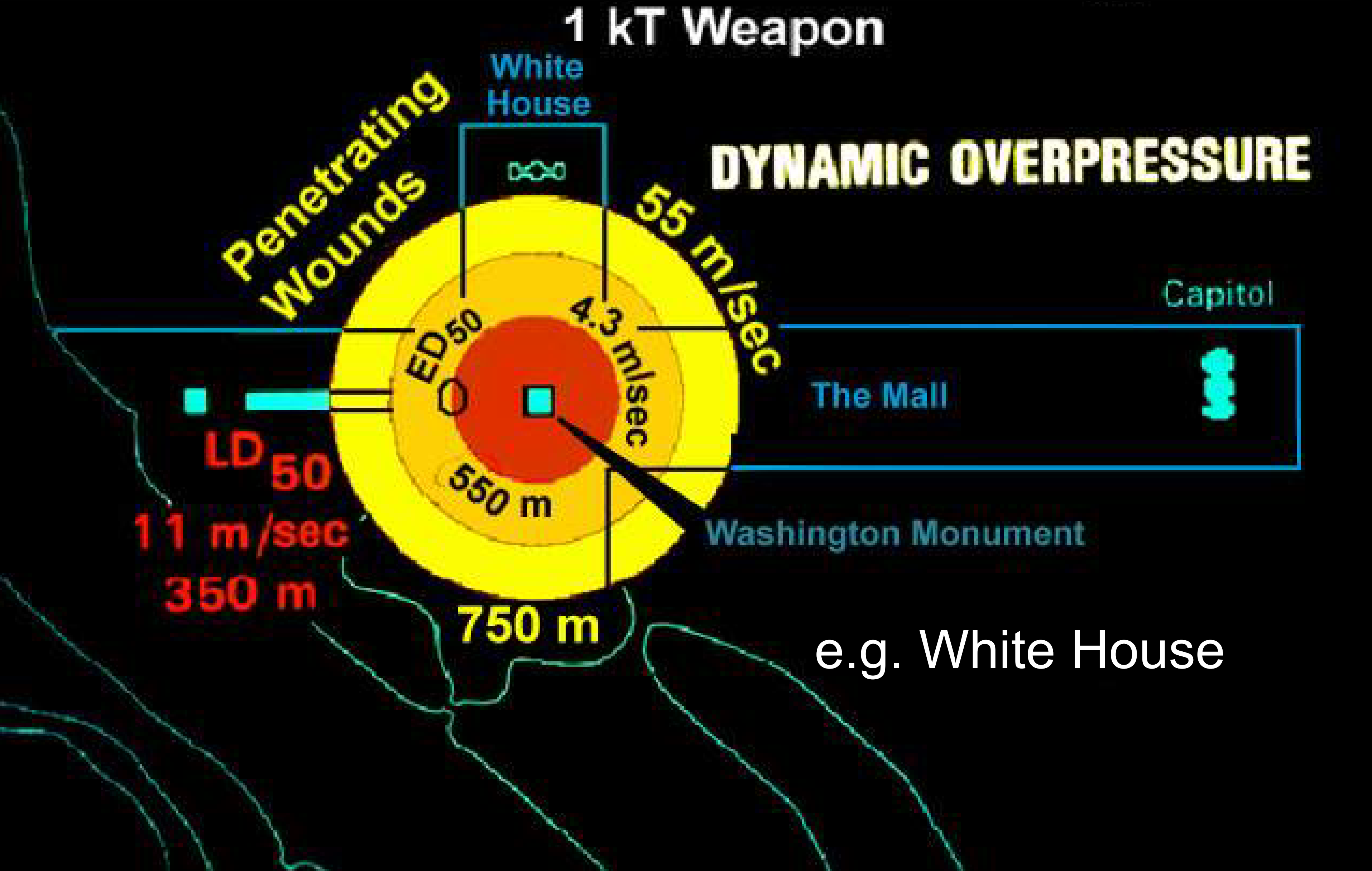
"one man's terrorist is another man's freedom fighter".

Conventional weapon based attack more likely; But a successful nuclear attack would provide high visibility and ensure long term impact.

Logistical problems include:
Generating nuclear material (^{235}U, ^{239}Pu); huge industrial effort requires breeder reactor and diffusion or centrifugal based separation facilities (~10-20 years)

Provision of nuclear bomb material (^{235}U, ^{239}Pu); only possible from stockpiles of exiting nuclear powers (Israel, Pakistan, North Korea) or leftover supplies from former nuclear powers (Kazakhstan, Uzbekistan, Ukraine). Not inconceivable!

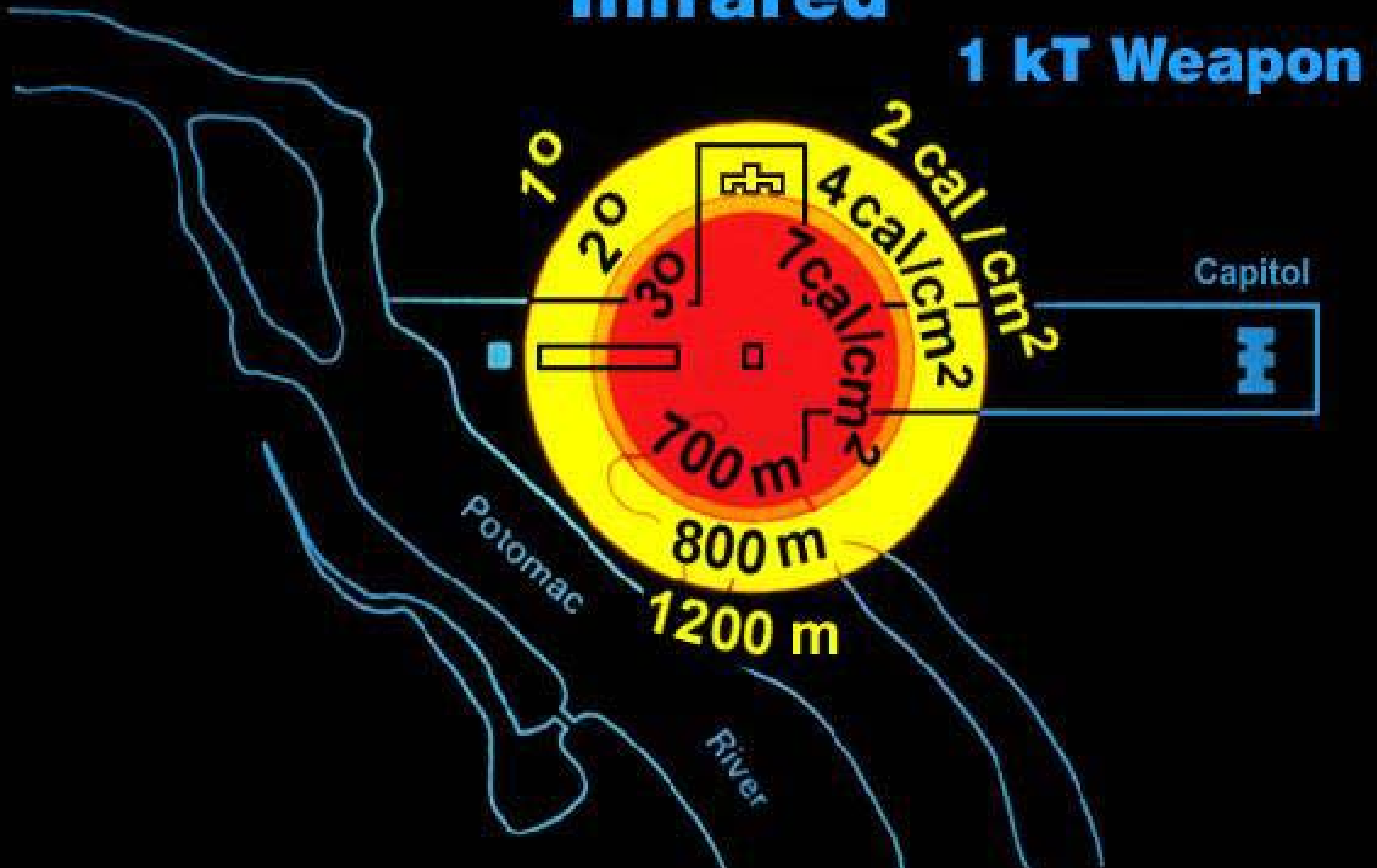
Preferred Target - High Visibility Object



e.g. White House

Effective Range for Thermal Energy Infrared

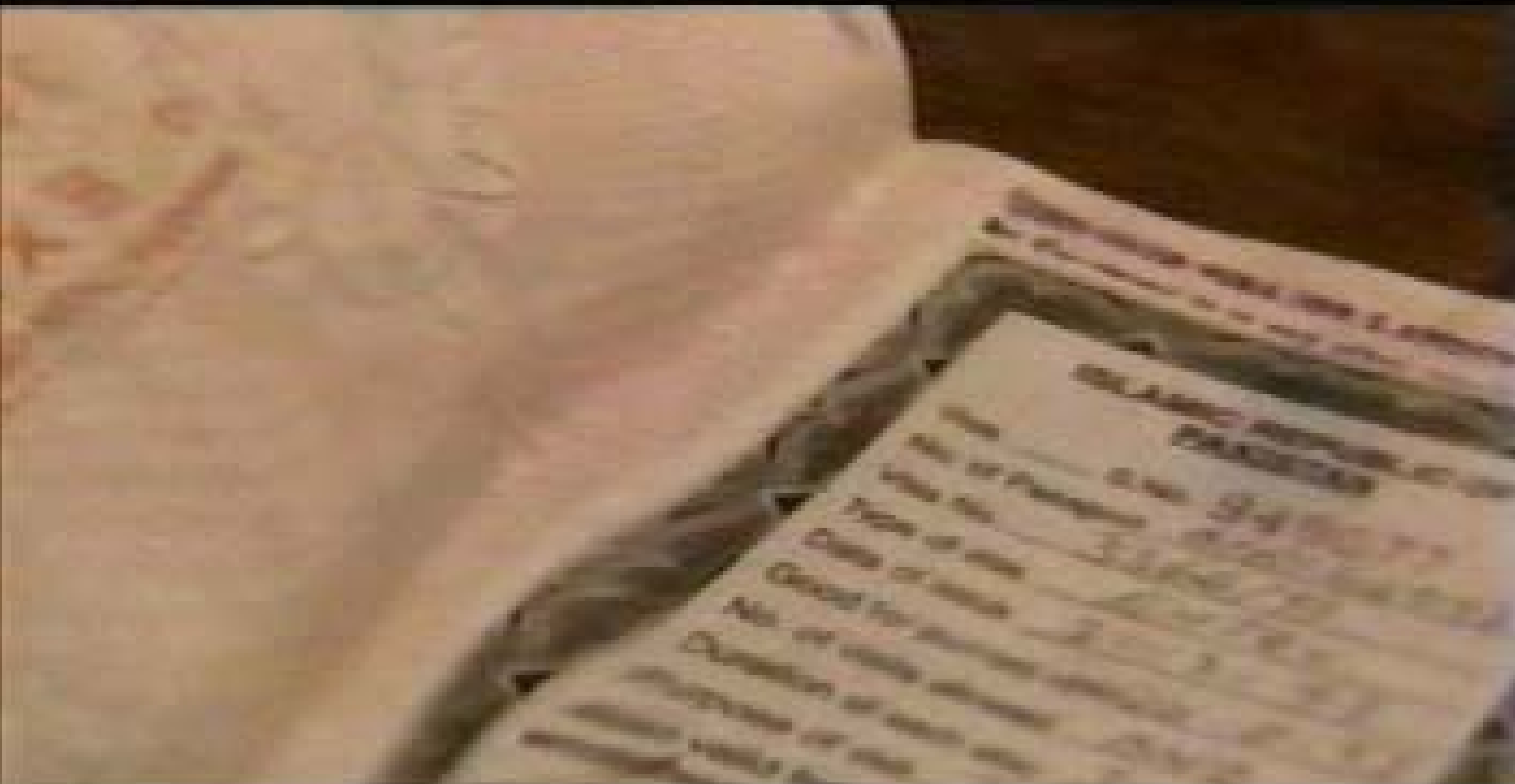
1 kT Weapon



Radiation effects would be limited to 10-20 km circle

Classical version seeks to enhance the production of long-term radioactivity by adding “seed material” for neutron capture, e.g. $^{59}Co(n,\gamma)^{60}Co$ – cobalt bomb.

The theorized **cobalt bomb** is, on the contrary, a radioactively "dirty" bomb having a cobalt tamper. Instead of generating additional explosive force from fission of the uranium, the cobalt is transmuted into ^{60}Co, which has a half-life of 5.26 y and produces energetic (and thus penetrating) γ rays. The half-life of ^{60}Co is just long enough so that airborne particles will settle and coat the earth's surface before significant decay has occurred, thus making it impractical to hide in shelters.



The New “Radiological” Version

The radiological dirty bomb would contain a small or medium amount of explosives (10 to 50 pounds [4.5 - 23 kg] of TNT, for example) with a small amount of low-level radioactive material (say a sample of ^{137}Cs or ^{60}Co from a university lab or more likely from a hospital radiology department).

To contaminate an area of 10,000m^2 (circle of ~60 m radius) with ~1 Ci/m^2 (<1 rad dose for by-passer) from material transported in a regular suitcase you need an initial source of ~10.000 Ci radioactive material in your explosive device. If the material is ^{60}Co this activity corresponds to ~90g of pure ^{60}Co. The dose rate is ~20 rad/s (depending how the carrier would hold the suitcase). For 1 h hike from terrorist headquarter to e.g. Times Square in New York the carrier would receive a lethal dose of 72000 rad. Major Pb shielding required for 1.076 and 1.33 MeV γ radiation from ^{60}Co radioactive decay. (A regular laboratory ^{60}Co source has an activity of <10^{-5} Ci.) An “effective” dirty bomb provides substantial logistical problems on the delivery side!

Identification of possible sources for larger amounts of radioactive material

Categorization of danger in terms of Activity/Dangerous activity A/D

activity: number of decays per time

radionuclide	TBq	Ci
^{60}Co	0.03	0.8
^{137}Cs	0.10	3.0
^{192}Ir	0.08	2.0
^{241}Am	0.06	2.0

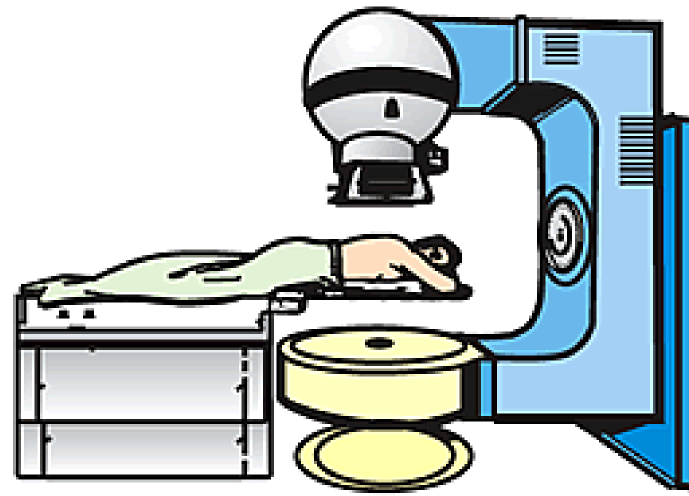
IAEA category of Dangerous Activity

Category	Practice	Activity ratio (A/D)
1	Radioisotope thermoelectric generators; irradiators; teletherapy; gamma knife	$A/D \geq 1{,}000$
2	Gamma radiography; brachytherapy (high/medium dose rate)	$1{,}000 > A/D \geq 10$
3	Fixed industrial gauges (e.g., level, dredger, conveyor gauges); well logging	$10 > A/D \geq 1$
4	Brachytherapy (low-dose rate except eye plaques and permanent implants); thickness/fill-level gauges; portable gauges, static eliminators, bone densitometers	$1 > A/D \geq 0.01$
5	Brachytherapy (eye plaques and permanent implants); x-ray fluorescence devices; electron capture devices	$0.01 > A/D \geq$ exempt/D

Highest risk is in “unprotected” medical facilities

Medical Sources

Sources are mainly designed for the radiation treatment of cancer patients

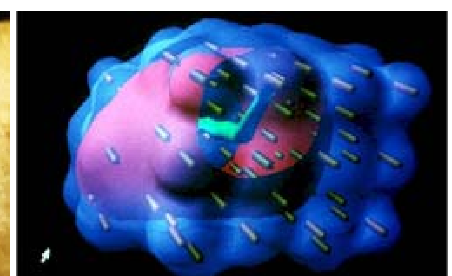


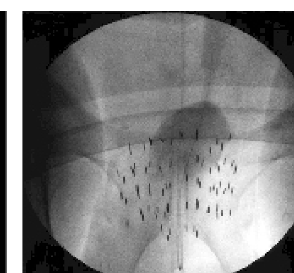
Cobalt-60 Teletherapy Unit

Theletherapy units

More than 10,000 medical sources of ^{60}Co ($T_{1/2}$≈5y), ~100 TBq ≈ 3000Ci each. Each capsule contains 10,000 pellets with each pellet 100 GBq

Third world countries prefer the less expensive ^{137}Cs sources ($T_{1/2}$≈30y) which comes as highly dispersible CsCl salt. Each unit contains ~100 TBq ≈ 3000Ci.





Brachytherapy units

Brachytherapy sources are more abundant but have lower individual radioactivity: ^{226}Ra, ^{137}Cs, and ^{192}Ir, with typical activity levels of 0.1-1.0GBq

Example for careless handling: Goiania, Brazil

A radiotherapy unit had been abandoned in a clinic which was being demolished. The unit had a source consisted of 1,375 curies of cesium-137 in the form of cesium chloride salt, sealed within two nested stainless steel containers to form a 5-cm diameter capsule. Two individuals dismantled the unit and extracted the source. Both began vomiting on 13 September. The unit material was sold to a junkyard, a blue glow from the source container was observed that night; a number of people came to view the capsule. On 21 September the source material was removed and distributed among several people, some of whom spread it on their skin. Around 23 September junkyard employees were exposed while further dismantling parts of the unit. …

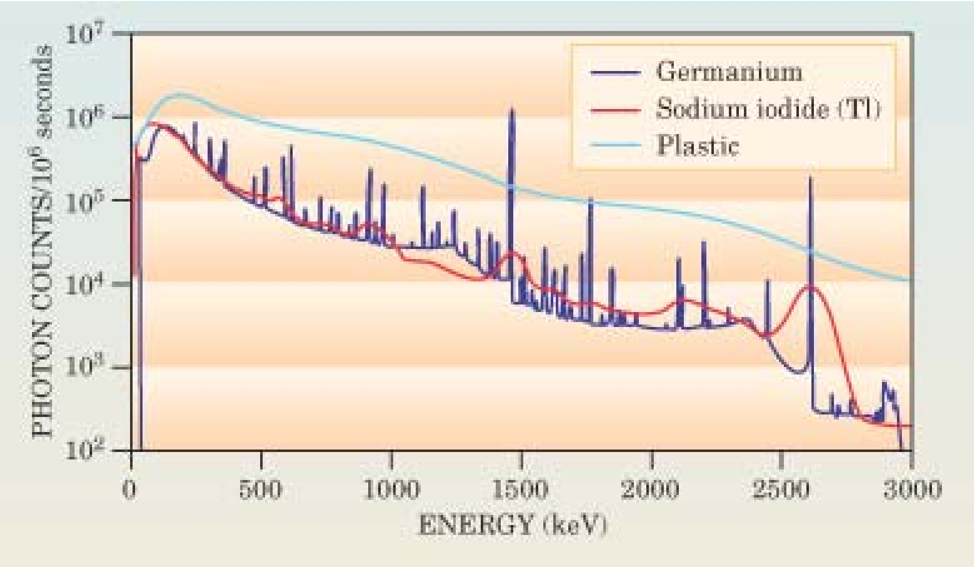
Dirty Bomb Scenario #1 (~2500 Ci)

Dirty Bomb Scenario #2 (~2500 Ci)

Requirements for being prepared for possible Al Qaeda dirty bomb threats

- Identification and localization for high activity radioactive sources (IAEA)
- Risk and threat assessment studies (IAEA + national agencies)
- Enhanced security requirements for high activity source storage against theft
- Enhanced security for international transport of radioactive material
- International legal agreements
- training of radiation control personal

Monitoring Radioactivity



Efficiency of 10^{-4} limits the detection to activities in the milli-Curie range

Problem with on-line radioactivity monitoring device is the number of false alarms due to natural activities and medical activities (patients after treatment)

Shortcomings and Limitations